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Durham, NC

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16. ABSTRACT

This report presents information on the emission levels, control techniques and costs associated with the control of particulate emission sources and facilities in the urea solids producing industry. Sources of emissions include prill towers, granulators and coolers. Alternative control techniques and supporting data are described and discussed, and an analysis of environmental and economic impacts of control techniques are presented.

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1.0 INTRODUCTION AND SUMMARY

1.1 PURPOSE

The purpose of this document is to present and discuss technical information on the emissions, control techniques, and costs associated with control of emissions from processes in the domestic urea industry. Results of uncontrolled and controlled emissions testing are presented to quantify uncontrolled emissions and evaluate control device performance.

1.2 SUMMARY

1.2.1 Industry Structure

The domestic urea industry produces urea in both solid and solution form. Solids are manufactured in two sizes. The smaller size is used for animal feed supplement. The larger sized solid is used for fertilizer applications and in the production of plastics and resins. Urea solutions are combined with other types of nitrogen solutions and used as fertilizers. There are 47 plants in the United States producing either urea solution alone or both solution and solids. In 1979 domestic urea production was 7.2 million Mg (9.9 million tons), a 19 percent increase over 1978.

1.2.2 Processes and Emissions

Unit processes in the urea industry include urea solution synthesis, solution concentration, solids formation (prilling and granulation), solids cooling, solids screening, solids coating, and bagging and/or bulk shipping. Uncontrolled particulate emission rates range from 0.00241 kg/Mg of product (0.00482 lb/ton) for urea solution synthesis and concentration to 148.8 kg/Mg of product (297.6 lb/ton) for a solids producing process (granulation). The most effective control device used to control urea particulate emissions is a wet scrubber.

1.2.3 Model Plants and Control Alternatives

Model plants were chosen to represent the existing domestic urea industry. These model plants have production capacities that range from

182 Mg/day (200 tons/day) to 1090 Mg/day (1200 tons/day). Control devices that exhibit various levels of removal efficiency were identified for each source. Removal efficiencies for control devices applied to the model plants range from 57.9 percent for a spray tower to 99.9 percent for a wet entrainment scrubber. Several control alternatives were identified for each model plant. The control alternatives are based upon combinations of control devices applied to the sources within the plant. Three control alternatives were identified for prilling plants and one for granulation plants. Table 1-1 summarizes the control alternatives and corresponding emission factors for the model plants.

1.2.4 Economic and Environmental Impacts

Table 1-2 presents a summary of impacts on urea product price due to the application of control alternatives. The increases in product price range from 2 to 8 percent based on a urea product price of \$132/Mg (\$120/ton). There are no water quality or solid waste impacts attributable to the use of wet scrubbers to control emissions. The primary air quality impact is the reduction in particulate emissions from sources in the urea industry. These reductions range from 58 to 98 percent for prill towers and 99.9 percent for granulators. Small secondary air impacts exist due to increased power plant particulate emissions resulting from the energy requirements of the control devices. The secondary impact relative to plant-wide emission reductions range from 1 percent for a granulation plant to 3 percent for a prilling plant.

TABLE 1-1. CONTROL ALTERNATIVES

Model Plant No.	Plant Configuration	Emission Sources	Control Alternatives			Control Alternatives - Emission Factors kg/Mg (lb/ton)		
			1	2	3	1	2	3
1-3	Nonfluidized bed, Agricultural grade prill production	Prill Tower	0	+	++	0.900	0.385	0.138
		Cooler	0	0	0	(1.800)	(0.770)	(0.276)
4-6	Fluidized bed, Agricultural grade prill production	Prill Tower	0	+	++	0.600	0.470	0.062
						(1.200)	(0.930)	(0.124)
7	Nonfluidized bed, Feed grade prill production	Prill Tower	0	+	++	0.800	0.270	0.036
						(1.600)	(0.540)	(0.072)
8-10	Granulator	Granulator	0			0.115	-	-
						(0.230)		

Legend: 0 - ELOC - defined in Chapter 5
+ - Option 1 - defined in Chapter 5
++ - Option 2 - defined in Chapter 5

TABLE 1-2. SUMMARY OF CONTROL ALTERNATIVES AND THEIR EFFECT ON PRODUCT PRICE

Model Plant No.	Size Mg/D (tons/D)	Configuration	Effect on Cost of Product $/Mg ($/ton) Control Alternative		
			1	2	3
1	181(200)	Nonfluidized prill tower plant producing agricultural grade prills.	6.35 (5.77)	7.20 (6.53)	10.31 (9.38)
2	726(800)		3.42 (3.11)	4.06 (3.68)	4.93 (4.48)
3	1090(1200)		2.93 (2.66)	3.68 (3.34)	4.39 (3.99)
4	181(200)	Fluidized bed prill tower plant producing agricultural grade prills	6.62 (6.02)	6.64 (6.03)	9.92 (9.02)
5	726(800)		3.73 (3.39)	4.79 (4.35)	5.77 (5.24)
6	1090(1200)		3.64 (3.31)	4.81 (4.36)	5.45 (4.95)
7	181(200)	Prill Tower Plant producing feed grade prills.	3.86 (3.51)	3.37 (3.06)	6.43 (5.85)
8	363(400)		[5.93][b] ([5.39])	–[a]	–[a]
9	726(800)	Granulation Plant	[6.03] ([5.46])	–[a]	–[a]
10	1090(1200)		[6.03] ([5.68])	–[a]	–[a]

---

[a] Control alternatives 2 and 3 are not presented for granulation plants.

[b] Values on brackets represent decreases in the product price.

2.0 THE UREA INDUSTRY

This chapter presents a description of the domestic urea industry. Section 2.1 will present information on the industry history, structure and growth. Section 2.2 will discuss urea products and end uses.

2.1 INDUSTRY STRUCTURE

The domestic urea industry consists of 47 plants operated by 36 firms. Geographically, the industry production capacity distribution has shifted during recent years. Prior to 1966, capacity was fairly evenly distributed throughout the country. However, as of 1979 the primary concentrations of production capacity lay in the South-central states and Alaska, which together accounted for 41 percent of the total domestic capacity.[1] This shift is attributed to the availability of natural gas supplies (the basic feedstock for urea production) in these regions.

Of the 36 urea producing firms, three firms account for over 39 percent of the total domestic urea production capacity. Table 2-1 presents a listing of all domestic producers, including their location, capacity, date of construction and product line. The majority of urea producers compete in the nitrogen fertilizer market with anhydrous ammonia, ammonium nitrate, ammonia, nitrogen solutions, and nitric acid. Urea's share of the domestic nitrogen fertilizer market has been steadily increasing since 1970. In 1979, solid urea accounted for 12 percent of the nitrogen fertilizer applied in the United States.

Historically, urea plants have operated at between 68 and 90 percent of their rated annual production capacity, depending on market conditions. Between 1966 and 1978 the average capacity utilization was 69.4 percent while in 1979 industry-wide capacity utilization increased to 90.2 percent.[2,3] In 1979, 7.2 million Mg (7.9 million tons) of urea was produced, a 19 percent increase over the previous year. The projected

TABLE 2-1. UREA PRODUCERS--PLANTS, LOCATIONS, AND CAPACITIES

Company name	Plant location	Capacity		Form of urea	Date on stream
		(10^3 Mg)	(10^3 tons)		
Air Products and Chemicals Inc.	Pensacola, FL	21	23	Solutions	1963
Allied Chemical Corp.	Helena, AR	61	67	Solutions	1967
	Geismar, LA	285	314	Solutions	1967
	Omaha, NB	127	140	Solutions	1955
American Cyanamid Co.	New Orleans, LA	120	132	Melamine	1966
Beker Industry Corp.[a]	Carlsbad, NM	160	176	Unspecified	1976
Bison Nitrogen Products (co-owned with Terra Chemical International)	Woodward, OK	104	114	Liquid feed	1978
Borden, Inc.	Geismar, LA	200	220	Prills	1968
CF Industries, Inc.	Donaldsonville, LA	788	867	Solutions, granular	1974
	Fremont, NB	16	18	Solutions	1965
	Olean, NY	68	75	Solutions, prills, liquid feed	1967
	Tunis, NC	150	165	Solutions	1969
	Tyner, TN	53	58	Solutions	1963
The Coastal Corp. Wycon Chemical Co.	Cheyenne, WY	54	59	Solutions, prills, liquid feed	1966
Columbia Nitrogen Corp.	Augusta, GA	359	395	Solutions, prills	1966
Cominco American Ltd. Camex, Inc.	Borger, TX	75	82	Granular, prills	1980
Enserch Corp. Nipak, Inc.	Kerens, TX	75	82	Unspecified	NA
Esmark, Inc. Estech General Chemicals Corp.	Beaumont, TX	45	50	Solutions	1967
Farmland Industries, Inc.	Dodge City, KS	58	64	Solutions	1975
	Lawrence, KS	244	268	Solutions, granular, liquid feed	1959
General American Oil Co. of Texas Premier Petrochemicals, subs.	Pasadena, TX	64	70	Prills	
Getty Oil Co. Hawkeye Chemical Co., subs.	Clinton, IA	55	60	Solutions	1963
Goodpasture, Inc.	Dimitt, TX	21	23	Solutions	1971
W.R. Grace and Co.	Memphis, TN	317	349	Prills, crystal	1955
Hercules Inc.	Louisiana, MO	86	95	Solutions, ureaform fertilizer	1958
Kaiser Aluminum & Chemical Co.	Savannah, GA	120	132	Solutions	1956

(continued)

[a] Currently shut down.

TABLE 2-1. (Continued)

Company name	Plant location	Capacity		Form of urea	Data on stream
		(10^3 Mg)	(10^3 tons)		
Mississippi Chemical Co.	Yazoo City, MS	127	140	Solutions, prills	1959
N-Ren Corporation	E. Dubuque, IL	77	85	Solutions, prills	1971
	Pryor, OK	16	18	Solutions	1970
Olin Corp.	Lake Charles, LA	164	180	Prills	1966
Phillips Pacific Chemical Co.	Finley, WA	34	37	Solutions	1965
Phillips Petroleum Co.	Beatrice, NB	48	53	Solutions	1965
Reichhold Chemicals	St. Helens, OR	93	102	Mostly prills	1967
J.R. Simplot Co.	Pocatello, ID	14	15	Solutions	1974
Standard Oil of CA Chevron Chemical Co.	Fort Madison, IA	66	73	Solutions	1980
Standard Oil of Ohio Vistron Corp., subs.	Lima, OH	200	220	Solutions, prills	1956
Tennessee Valley Authority	Muscle Shoals, AL	55	60	Solutions, granular	1972
Terra Chemical International	Port Neal, IA	230	253	Solutions, granular, prills, liquid feed	1967
Triad Chemicals	Donaldsonville, LA	426	469	Prills, melamine	1968
Tyler Corp. Atlas Powder Corp., subs.	Joplin, MO	67	74	Solutions, prills	1961
Union Oil of California	Brea, CA	109	120	Solutions, prills	1966
	Kenai, AK	680	748	Granular, prills	1969
U.S. Steel Corp.	Cherokee, AL	70	77	Solutions	1962
Valley Nitrogen Producers	El Centro, CA	135	148	Solutions, prills, liquid feed	1968
Williams Co. Agrico Chemical Co.	Blytheville, AR	300	330	Granular	1975
	Donaldsonville, LA	205	226	Granular	1968
	Verdigris, OK	480	528	Solutions	1975

demand for urea in 1980 is 7.5 million Mg (8.2 million tons) which would represent a 4 percent increase in production over 1979.[4]

2.2 UREA PRODUCTS AND END USES

Urea has three basic uses: fertilizer, cattle feed, and as a component in the manufacture of plastics and resins. Table 2-2 presents the annual amount of urea used for fertilizer, feed, and plastics and other applications.

Urea is marketed as a solution or in a variety of solid forms. Most urea solution is used in fertilizers, with a small amount going to animal feed supplements. Urea solution is never used alone as a fertilizer. It is always blended prior to application with another chemical such as ammonium nitrate or ammonium sulfate. Mixed urea-ammonium nitrate (UAN) solutions have a number of advantages over pure urea or ammonium nitrate solutions. UAN solutions are less corrosive than either of the individual components and do not decompose with time like pure urea solution. Most importantly, UAN solutions have a lower crystallization temperature than ammonium nitrate or urea solutions separately, which reduces the likelihood of a solution salting out during transfer and application. Solution fertilizers are currently becoming more popular than solid fertilizer because they are easier to transfer in tank cars and do not generate dust problems.[5,6] However, solid urea is still in demand for various applications.

Urea solids are produced as prills, crystals, and granules. A prill is an air-cooled solid sphere that is produced in two sizes. The smaller of these, 0.35-1.7 mm (0.014 - 0.066 in) in diameter, is referred to as feed grade and the larger, 0.5 - 4.0 mm (0.020 - 0.157 in), as agricultural (or fertilizer) grade urea. Prills are used as a fertilizer, as a protein supplement in animal feeds, and in plastics manufacturing. Feed grade urea production has declined since 1960 when 12.9 percent of total urea production was feed grade urea. By 1978 feed grade urea represented only 6.7 percent of total urea production. The major urea based plastics are urea-formaldehyde resins and melamine. The domestic output of urea for use in the manufacture of plastics has grown steadily

TABLE 2-2. UREA PRODUCTION BY USE[7]
10^3 Mg[a]

	Fertilizer			Animal Feed	Plastics & other	Total
	Liquid	Solid	Total			
1956			134.18	NA	NA	NA
			(148.60)			
1957			169.19	NA	NA	NA
			(186.11)			
1958			223.64	NA	NA	NA
			(246.00)			
1959			213.91	NA	NA	NA
			(235.30)			
1960	223	274	497.00	86	83	666
	(245)	(301)	(546.70)	(95)	(91)	(733)
1961	284	382	666.00	92	78	836
	(312)	(420)	(732.60)	(101)	(86)	(920)
1962	310	423	733.00	101	82	916
	(341)	(465)	(806.30)	(111)	(90)	(1,008)
1963	341	434	775.00	115	101	991
	(375)	(477)	(852.50)	(126)	(111)	(1,090)
1964	394	495	889.00	108	99	1,096
	(433)	(544)	(977.90)	(119)	(109)	(1,206)
1965	428	496	924.00	136	107	1,167
	(471)	(546)	(1,016.40)	(150)	(118)	(1,284)
1966	604	629	1,233.00	175	149	1,557
	(664)	(692)	(1,356.30)	(192)	(164)	(1,713)
1967	748	794	1,542.00	210	145	1,897
	(823)	(873)	(1,696.20)	(231)	(160)	(2,087)
1968	903	893	1,796.00	256	156	2,208
	(993)	(982)	(1,975.60)	(282)	(172)	(2,429)
1969	1,002	1,226	2,228.00	304	163	2,695
	(1,102)	(1,239)	(2,450.80)	(334)	(179)	(2,964)
1970	1,278	1,090	2,368.00	305	156	2,729
	(1,406)	(1,199)	(2,604.80)	(336)	(172)	(3,002)
1971	1,182	953	2,135.00	248	452	2,835
	(1,300)	(1,048)	(2,348.50)	(273)	(497)	(3,118)
1972	1,148	1,195	2,343.00	308	494	3,145
	(1,263)	(1,314)	(2,577.30)	(339)	(543)	(3,460)
1973	1,121	1,321	2,442.00	371	401	3,214
	(1,233)	(1,453)	(2,686.20)	(408)	(441)	(3,535)
1974	1,221	1,302	2,523.00	342	573	3,438
	(1,343)	(1,432)	(2,775.30)	(376)	(630)	(3,782)
1975	1,309	1,358	2,667.00	264	514	3,445
	(1,440)	(1,494)	(2,933.70)	(290)	(565)	(3,790)
1976	1,029	1,894	2,923.00	222	556	3,701
	(1,132)	(2,083)	(3,215.30)	(244)	(612)	(4,071)
1977	1,336	2,434	3,770.00	216	614	4,600
	(1,470)	(2,677)	(4,147.00)	(238)	(675)	(5,060)
1978			4,605.00	334[b]	NA	4,939
			(5,065.50)	(367)[b]		(5,433)
1979			5,236.00	342[b]	NA	6,147
			(5,760.00)	(376)[b]		(6,762)

[a] Numbers in parentheses are in 10^3 tons.

[b] Includes all products other than fertilizer.

Totals not exact due to rounding.

since 1960 at an annual average growth rate of 11.8 percent.[8] Currently, 8 percent of the total urea produced is targeted for uses in plastics, resins and melamine.[5]

Crystals are formed by the vacuum crystallization and drying of urea solution. These crystals may be used as is, or remelted for prilling. The major advantage of crystals is their lower biuret content. Biuret is a urea decomposition product and a plant poison (see Chapter 3).

Production of agricultural grade urea solids by granulation is on the increase compared to production by prilling. In granulation, seed particles are built up to granules by the addition of successive layers of molten material. Because of the nature of particle buildup, granulation can produce larger particles with greater abrasion resistance and particles with two or three times the crushing strength of standard prills. Another benefit of greater abrasion resistance is the reduction of solids dusting when the product is conveyed and bulk loaded. Granular product is not as spherical or as smooth as the prilled product, and small feed grade granules cannot be manufactured using present technology.[9] However, any of the larger desired product sizes, from fertilizer grade granules to even larger forestry grade granules can be manufactured. Large granules are preferred for forestry application because they are more massive and less likely to be caught in tree branches when being applied from the air.[5]

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3.0 PROCESSES AND THEIR EMISSIONS

This chapter presents a discussion of the processes and emissions found in the urea industry. Section 3.1 will present the urea process chemistry, a process overview, a description of the types of urea plants, and emissions overview. Section 3.2 will discuss in detail the individual urea production processes and their emissions.

3.1 INTRODUCTION

3.1.1 Process Chemistry

Urea (also known as carbamide or carbonyl diamide) $CO(NH_2)_2$ is an organic, natural gas based chemical. The primary feedstocks of urea are ammonia and carbon dioxide. Urea is formed by reacting ammonia and carbon dioxide at 448-473 K (347-392°F) and 19.2-23.2 MPa (2,800-3,400 psi) to form ammonium carbamate. The carbamate is then dehydrated to form urea and water. These reactions are represented by the following equations.

$$2NH_3 + CO_2 \longrightarrow NH_4CO_2NH_2 \qquad (1)$$

$$NH_4CO_2NH_2 \longrightarrow NH_2CONH_2 + H_2O \quad (2)$$

The carbamate formation step (1) is exothermic, releasing 150-160 kJ (64500-68800 Btu) per mole of ammonium carbamate formed. This reaction is favored by high pressures. The dehydration step (2) is endothermic, consuming 32 kJ (13800 BTU) per mole of urea formed. This step is favored by high temperatures.[1]

Urea, as a solid, is a colorless crystal with a melting point of 406 K (271°F) and a specific gravity of 1.335 at 293 K (68°F).[2,3] Aqueous urea solutions begin to decompose at 333 K (140°F) to buiret and ammonia. Dry urea, however, is stable below 403K (266°F). Above this temperature dry urea decomposes to buiret and ammonia according to the following reaction.

$$2CO(NH_2)_2 \longrightarrow (NH_2CO)_2\ NH + NH_3$$

Above 443K (338°F) the primary decomposition products of urea are cyanuric acid $(HNCO)_3$ and ammonia.

The biuret concentration in urea must be monitored, as it is a plant poison, and is also undesirable in industrial (plastics) applications. Biuret concentrations in urea solids are 0.1 percent or less in crystals, 0.3 percent in solids formed from crystal remelt, and 1.0 percent in solids formed from concentrated urea solution.[4]

3.1.2 Process Overview

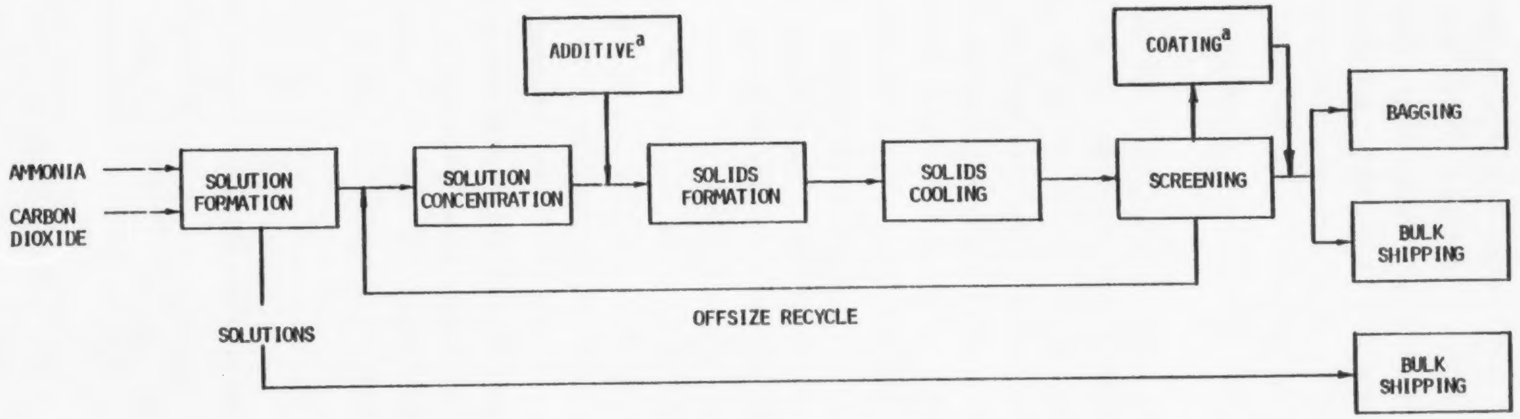
The process for manufacturing urea involves a combination of up to seven major unit operations. The basic arrangement of these operations is shown in the block diagram given in Figure 3-1. These major operations are:

(1) solution synthesis (solution formation)
(2) solution concentration
(3) solids formation
    - prilling
    - granulation
(4) solids cooling
(5) solids screening
(6) solids coating
(7) bagging and/or bulk shipping

The combinations of processing steps are determined by the desired end products. Plants producing urea solutions alone are comprised of only the first and seventh unit operations, solution formation and bulk shipping. Facilities producing solid urea employ these two operations and various combinations of the remaining five operations, depending upon the specific end product being produced.

3.1.3 Types of Urea Plants

All urea plants produce an aqueous urea solution as depicted in the process diagram shown in Figure 3-1. In these plants, ammonia and carbon dioxide are reacted to form ammonium carbamate. The carbamate is then dehydrated to yield a 70 to 77 percent aqueous urea solution. The



[a] These processes are optional depending on individual manufacturing practices.

Figure 3-1. Urea manufacturing.

solution can be sold as an ingredient in nitrogen solution fertilizers or can be further concentrated to produce solid urea. There are three methods of concentrating urea solution: vacuum evaporation, atmospheric evaporation and crystallization. Vacuum and atmospheric evaporation produce a urea melt containing from 99 to 99.9 percent urea at a nominal temperature of 413.7K (285°F). Crystallization is used primarily when product requirements dictate an extremely low biuret concentration in the final product.

Urea solids are produced from the urea melt by two basic methods: prilling and granulation. In prilling there are two types of prill towers: fluidized bed and nonfluidized bed. Each of these is capable of producing both agricultural grade and feed grade urea prills. The major difference between these towers is that a separate solids cooling operation may be required when producing agricultural grade prills in a nonfluidized bed prill tower. The fluidized bed supplies the required cooling for agricultural prills in a fluidized bed prill tower. However, because the small feed grade prills exhibit better heat transfer properties, additional cooling external to the nonfluidized bed tower is not required. Prill towers are described in detail in Section 3.2.4.

The other methods of solids formation used in the urea industry are drum and pan granulation. In drum granulation, solids are built up in layers on seed granules in a rotating drum granulator/cooler approximately 14 feet in diameter. Pan granulators also form the product in a layering process, but the equipment used is different from the drum granulator. There is only one pilot scale pan granulator operating in the domestic industry, providing 61,000 Mg/year (67,000 tons/year) of urea granules. Details of the granulation process are presented in Section 3.2.5.

3.1.4 Industry Emissions Overview

Emissions from urea processes include particulate matter, ammonia and formaldehyde. Table 3-1 presents uncontrolled emission factors for each of the major processes in the urea industry. Table 3-2 provides an

TABLE 3-1. UNCONTROLLED EMISSIONS FROM UREA FACILITIES[a],[5]

Process	Plant	Particulate kg/Mg	Particulate (lb/ton)	Ammonia kg/Mg	Ammonia (lb/ton)	Formaldehyde kg/Mg	Formaldehyde (lb/ton)
Solution Formation and Concentration	A	0.00241	(0.00482)	12.89	(25.77)	-	
Solution Formation and Concentration	B	0.0150	(0.0317)	4.01	(8.02)	-	
Solution Formation and Concentration	D	0.0052	(0.0104)	14.40	(28.80)	-	
Drum Granulation	A	148.8	(297.6)	1.08	(2.15)	0.00359	(0.0072)
Drum Granulation	B	63.6	(127.2)	1.07	(2.13)	0.00555	(0.0111)
Non-Fluidized Bed Prill Tower (Agricultural Grade)	E	1.90	(3.80)	0.433	(0.865)	-	
Fluidized Bed Prill Tower (Feed Grade)	D	1.80	(3.60)	2.07	(4.14)	0.0020	(0.0040)
Fluidized Bed Prill Tower (Agricultural Grade)	D	3.12	(6.23)	1.42	(2.91)	0.0095	(0.0190)
Rotary Drum Cooler	C	3.72	(7.45)	0.0255	(0.051)	-	

[a] All data are from EPA test results (see Appendix A).

estimate of the total annual emissions from sources in typical urea plants based on the emission factors in Table 3-1.

Ammonia is emitted during urea synthesis (solution production) and solids production processes. Ammonia emissions range from 14.40 kg/Mg (28.80 lb/ton) for synthesis processes to 0.0255 kg/Mg (0.0051 lb/ton) for a rotary drum prill cooler. A more detailed list of ammonia emission data are presented in Appendix A.

Formaldehyde has been added to the urea melt in recent years for the purpose of reducing urea dust emissions and to prevent solid urea product from caking during storage. Formaldehyde is added to the urea melt in concentrations of 0.5 percent or less prior to solids formation. A further discussion on additives is contained in Section 3.2.8. The use of formaldehyde as an additive has resulted in formaldehyde emissions which range from 0.0095 kg/Mg (0.0190 lb/ton) of urea produced for a fluidized bed prill tower producing agricultural grade urea, to 0.0020 kg/Mg (0.0040 lb/ton) of urea produced for a fluidized bed prill tower producing feed grade urea solids. A more detailed list of formaldehyde emissions is included in Appendix A.

Particulate matter is the primary emission being addressed in this report. Table 3-1 includes a summary of uncontrolled particulate emissions form all urea processes. These particulate emissions range from 148.8 kg/Mg (297.6 lb/ton) of urea produced for a rotary drum granulator to 0.00241 kg/Mg (0.00482 lb/ton) of urea produced for a synthesis process. A more detailed list of particulate emissions is presented in Appendix A.

In the following section each of the processing steps described earlier is reviewed. Several of these processes are comparatively small particulate emitters and/or are not expected to be built in the future because of changing production technology. For these processes, the sections will provide a brief description of the actual process operations. More detailed descriptions are provided for solids production and cooling processes which are large particulate emitters.

TABLE 3-2. ESTIMATED ANNUAL UNCONTROLLED EMISSIONS FROM PROCESSES IN TYPICAL UREA PLANTS[a] Mg (Tons)

Process	Plant Capacity Mg/day	(tons/day)	Particulate		Ammonia		Formaldehyde	
Solution Formation and Concentration	363	(400)	0.342	(0.377)	1142	(1258)	—[b]	
Solution Formation and Concentration	727	(800)	0.686	(0.755)	2284	(2516)	—[b]	
Solution Formation and Concentration	1090	(1200)	1.028	(1.132)	3427	(3773)	—[b]	
Drum Granulation	363	(400)	11304	(12499)	116.9	(128.8)	0.00831	(0.00915)
Drum Granulation	727	(800)	22608	(24898)	233.9	(257.7)	0.0166	(0.0183)
Drum Granulation	1090	(1200)	33911	(37348)	350.9	(386.5)	0.0249	(0.0275)
Non-Fluidized Bed Prill Tower (Agricultural Grade)	182	(200)	103.8	(114.4)	23.60	(26.04)	—[c]	—[c]
Non-Fluidized Bed Prill Tower (Agricultural Grade)	363	(400)	207.7	(228.8)	44.2	(52.08)	—[c]	—[c]
Non-Fluidized Bed Prill Tower (Agricultural Grade)	727	(1800)	415.5	(457.6)	88.5	(104.16)	—[c]	—[c]
Non-Fluidized Bed Prill Tower (Agricultural Grade)	1090	(1200)	623.3	(686.3)	141.8	(156.24)	—[c]	—[c]
Fluidized Bed Prill Tower (Agricultural Grade)	182	(200)	162.4	(178.3)	76.0	(83.7)	0.492	(0.542)
Fluidized Bed Prill Tower (Agricultural Grade)	363	(400)	324.7	(357.6)	152.9	(167.4)	0.984	(1.0836)
Fluidized Bed Prill Tower (Agricultural Grade)	727	(800)	487.1	(536.4)	304.0	(334.7)	1.968	(2.167)
Fluidized Bed Prill Tower (Agricultural Grade)	1090	(1200)	730.6	(804.5)	456.0	(502.1)	2.953	(3.251)
Fluidized Bed Prill Tower (Feed Grade)	182	(200)	91.8	(101.1)	108.5	(119.5)	0.104	(0.114)
Fluidized Bed Prill Tower (Feed Grade)	363	(400)	183.6	(202.3)	217.0	(239.0)	0.208	(0.229)
Fluidized Bed Prill Tower (Feed Grade)	727	(800)	367.2	(404.5)	434.0	(478.0)	0.416	(0.458)
Fluidized Bed Prill Tower (Feed Grade)	1090	(1200)	550.8	(606.8)	651.0	(717.0)	0.621	(0.686)
Rotary Drum Cooler	182	(200)	213.2	(234.8)	1.39	(1.54)	—[c]	—[c]
Rotary Drum Cooler	363	(400)	426.4	(469.6)	2.78	(3.07)	—[c]	—[c]
Rotary Drum Cooler	727	(800)	852.8	(939.1)	5.55	(6.14)	—[c]	—[c]
Rotary Drum Cooler	1090	(1200)	1279.2	(1408.7)	8.33	(9.21)	—[c]	—[c]

[a] Plant capacities are presented for comparison purposes only and do not necessarily represent the actual capacity of the tested process.

[b] Formaldehyde is introduced to the melt after solution formation and concentration processes.

[c] Not available.

3.2 DESCRIPTION OF PROCESSES AND EMISSIONS

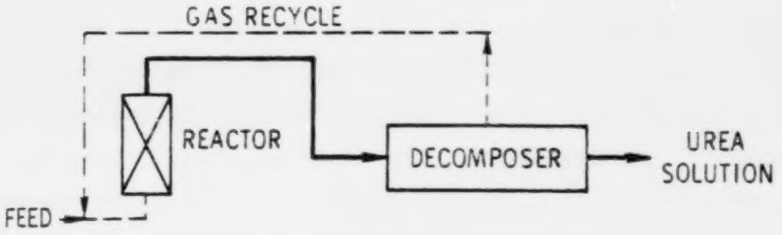
3.2.1 Synthesis Processes

There are numerous process designs for producing urea solution. These designs fall into 3 categories, they are once-through processes, partial-recycle processes, and total recycle processes.[6]

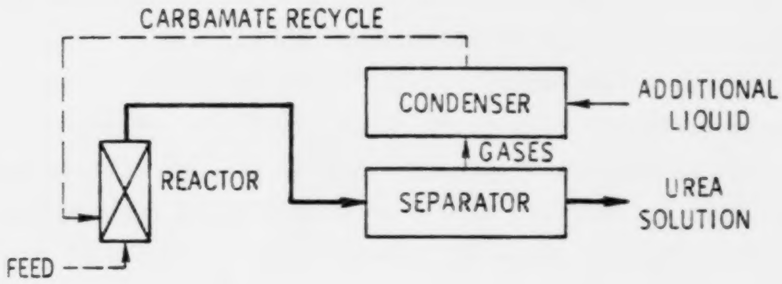
The older processes are the once-through and partial-recycle processes, dating back to the early 1950's. These processes represent less than 25 percent of current domestic urea production capacity.[6] The once-through process employs a reactor and a carbamate decomposer. The decomposer separates urea solution from a stream containing ammonia, carbon dioxide, and water. This ancillary stream is generally sent to another fertilizer-producing plant. The partial-recycle process provides a small refinement in that excess ammonia from the urea reactor is recovered and recycled to the reactor. Ammonia excesses as large as 200 percent are used to boost urea yields up to 80 percent.[7]

The total recycle process is the most widely used of the basic processes since it provides the benefits of higher yields and lower energy consumption. Major designers of urea synthesis plants have three types of total recycle process: (1) processes in which decomposed carbamate gases are separated and recycled to the reactor (Figure 3-2a); (2) processes in which carbamate solution is recycled (Figure 3-2b); and (3) processes in which both gas and liquid recycling is used (Figure 3-2c). At least ten major companies provide designs within these total recycle process classifications.[8]

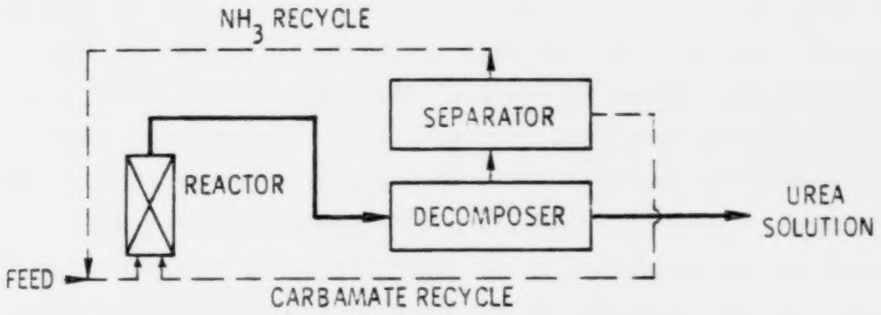
Emission sources from synthesis processes are typically noncondensable vent streams from ammonium carbamate decomposers and separators. Emissions from synthesis processes are generally combined with emissions from the solution concentration process. Results of EPA testing on these emissions are presented in Table 3-1 and Appendix A. Based on EPA testing, combined particulate emissions from urea synthesis and concentration are small compared with particulate emissions from a typical solids producing urea plant. For this reason, emissions from synthesis processes will not be considered further in this report.



A. Basic gas recycle process



B. Basic liquid recycle process



C. Basic gas / liquid recycle process

— PRODUCT-CONTAINING STREAMS
- - - RECYCLE, FEED, OR OTHER ANCILLARY STREAMS

Figure 3-2. Total recycle urea processes.[9]

3.2.2 Solution Concentration

The 70 to 77 percent urea solution resulting from the synthesis process must be concentrated if a solid urea product is desired. The method of concentration depends upon the level of biuret impurity allowable in the end product. For low biuret urea, solution concentration is effected by means of continuous crystallization in an atmospheric or vacuum crystallizer. The solution is concentrated at moderate temperatures until urea is crystallized from solution. The crystals are separated from solution and are dried as a product or remelted for further processing. Vacuum is often developed by use of steam ejectors. At present, only five manufacturing plants employ crystallization, and at least one facility has eliminated the crystallization process.[10,11]

Solution concentration to greater than 99 percent urea is more often accomplished by means of single or double stage evaporation. Evaporators operating at atmospheric pressure are commonly of the thin film or falling film variety as shown in Figure 3-3. Newer processes employ vacuum evaporators, typically of the thermosiphon and forced circulation design as illustrated in Figure 3-4. These evaporators operate at slightly higher temperatures than the crystallization process and provide a nearly pure urea melt to the solids formation process. Again, vacuum is provided by means of steam ejectors.[12,13,14]

Noncondensable emissions from solution concentration processes are often combined with emissions from the synthesis process and vented in a common stack. Particulate emissions from concentration processes are small compared to those from other plant processes. For this reason, emissions from concentration processes will not be discussed further in this report.

3.2.3 Prilling

Prilling is a process by which solid, nearly spherical particles are produced from molten urea. Molten urea is sprayed from a head tank into the top of a rectangular or circular tower (See Figures 3-5 and 3-6). As the droplets fall through a countercurrent air flow, they are cooled

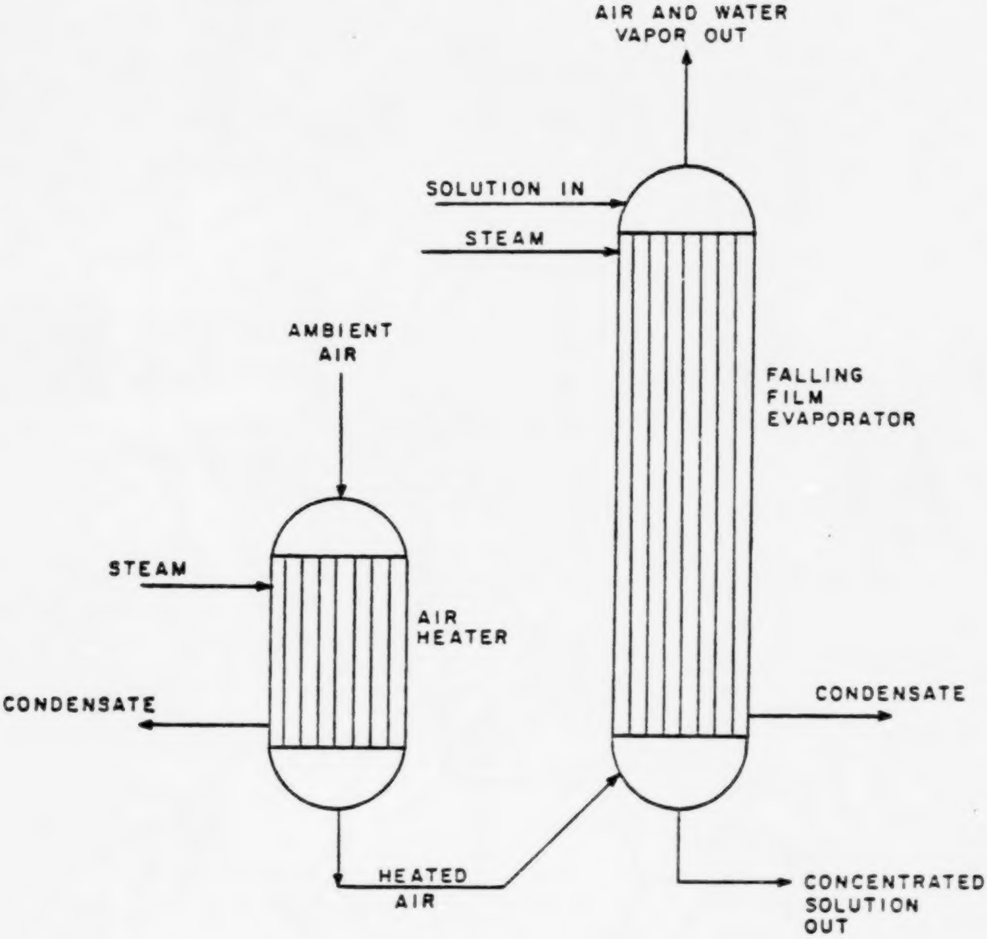


Figure 3-3. Air swept falling film evaporator.

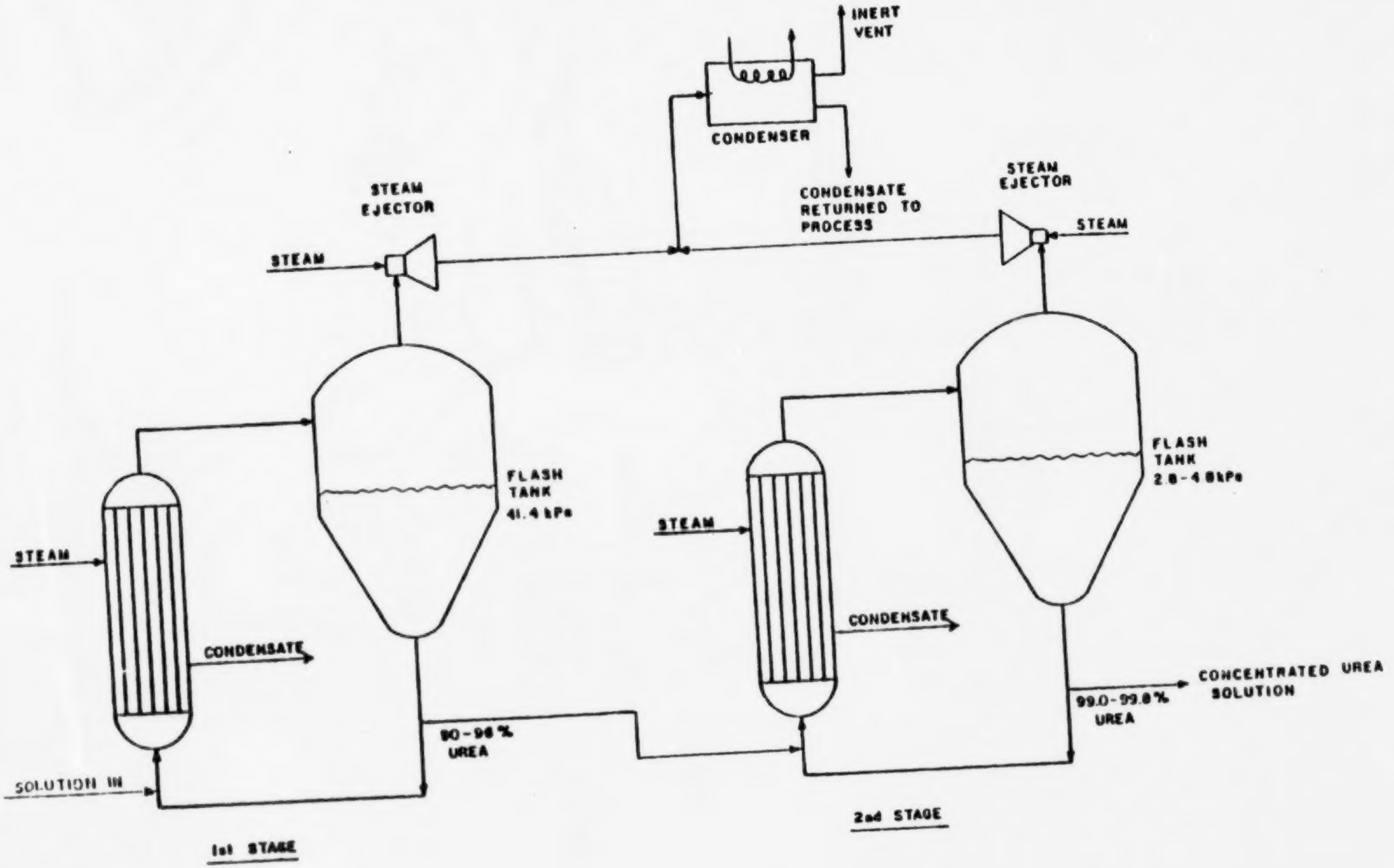


Figure 3-4. Two-stage vacuum evaporator.

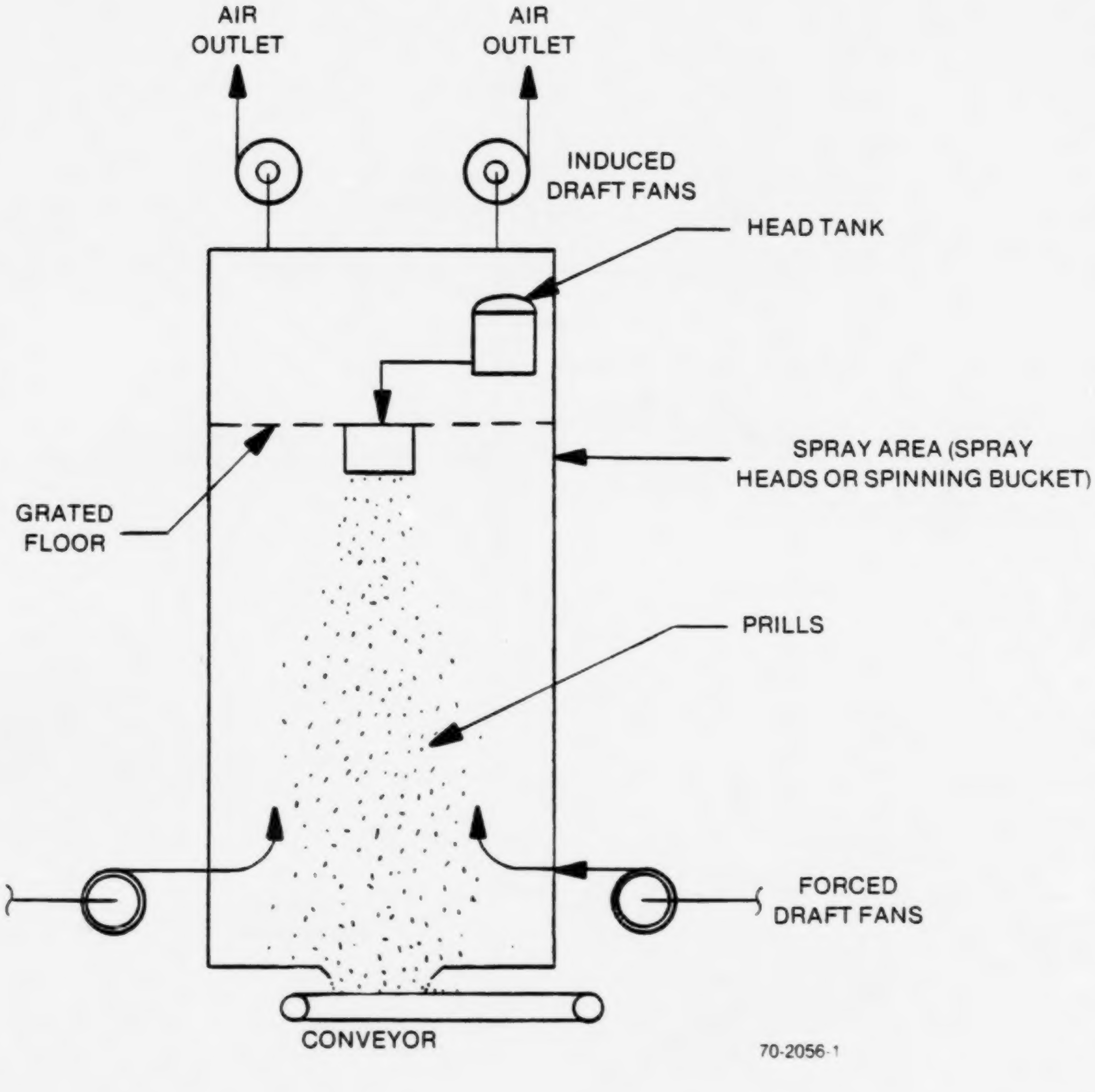


Figure 3-5. Prill tower - nonfluidized bed.

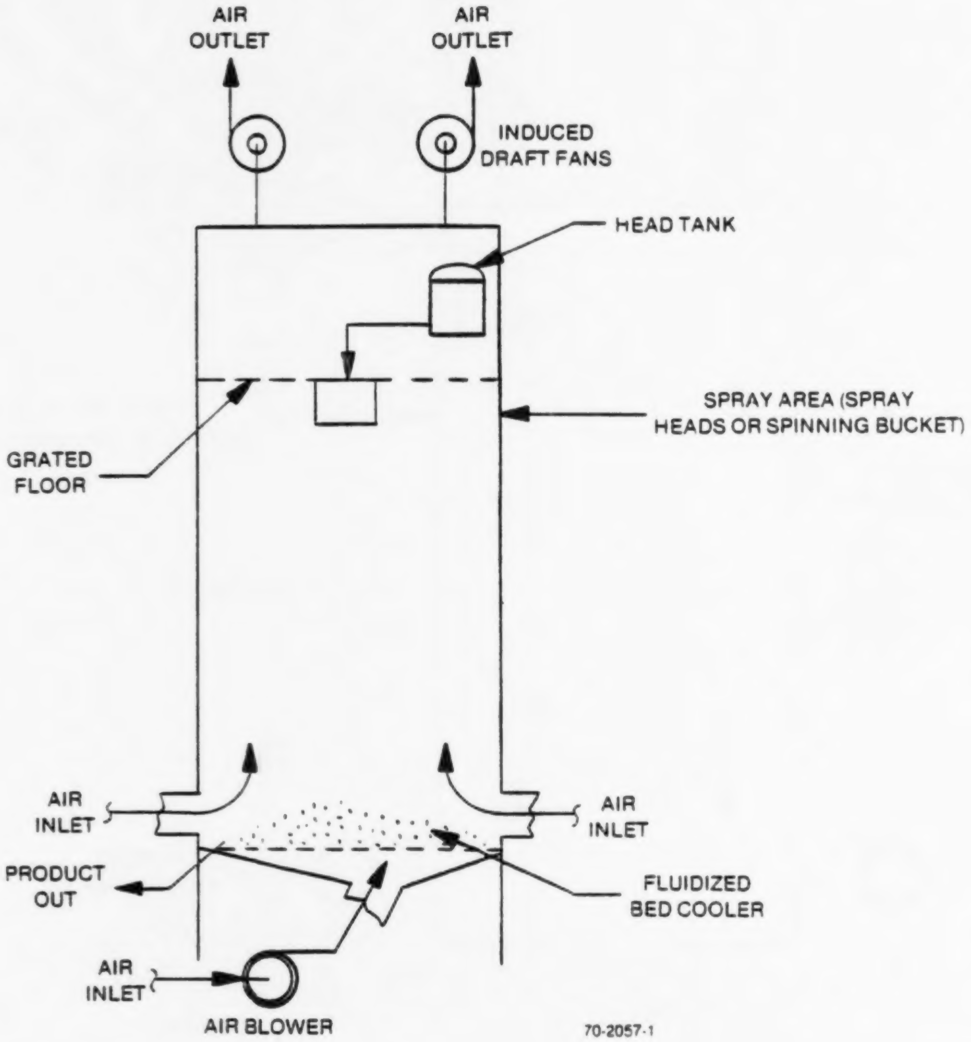


Figure 3-6. Prill tower fluidized bed.

and solidify into near-spherical particles. The solids are collected at the bottom of the tower for further processing.

Prill towers typically range from 33.5 meters (110 feet) to 64 meters (210 feet) in height. Cross sectional areas range from 29.2 square meters (314 square feet) to 190 square meters (2040 square feet). The height and cross sectional area of a prill tower depend upon prilling rate, product grade produced and the amount of cooling required. Molten urea between 99.5 and 99.8 percent in concentration is sprayed into the prill tower at about 413K (284°F) by either a single spinning bucket (see Figure 3-7) or a spray head arrangement (see Figure 3-8).

Natural, forced or induced draft may be used to provide air flow through the tower. The airflow rate for cooling of the prills depends upon ambient temperature and humidity, prilling rate and type of prills being produced.[15] If the tower incorporates a fluidized bed cooler, the blower used to suspend the prill bed supplies air to the main body of the tower as well.

Uncontrolled emission rates from prill towers may be affected by the following factors:

1. product grade being produced (agricultural grade or feed grade)
2. air flow rate through the tower
3. type of tower bed
4. ambient air conditions and
5. melt spray conditions

These factors are described in this section.

Two different size prills are produced by industry: feed grade and agricultural grade. The hole diameter in the sprayhead or bucket determines the size of the prill being produced,[16] which in turn determines the airflow rate required for cooling in the tower. Generally, 60 to 70 percent lower airflow rates are required when smaller sized feed grade urea is being produced. The smaller particle size results in better heat transfer because of the larger surface area per unit volume of urea. Although grain loadings are higher in the exhaust streams

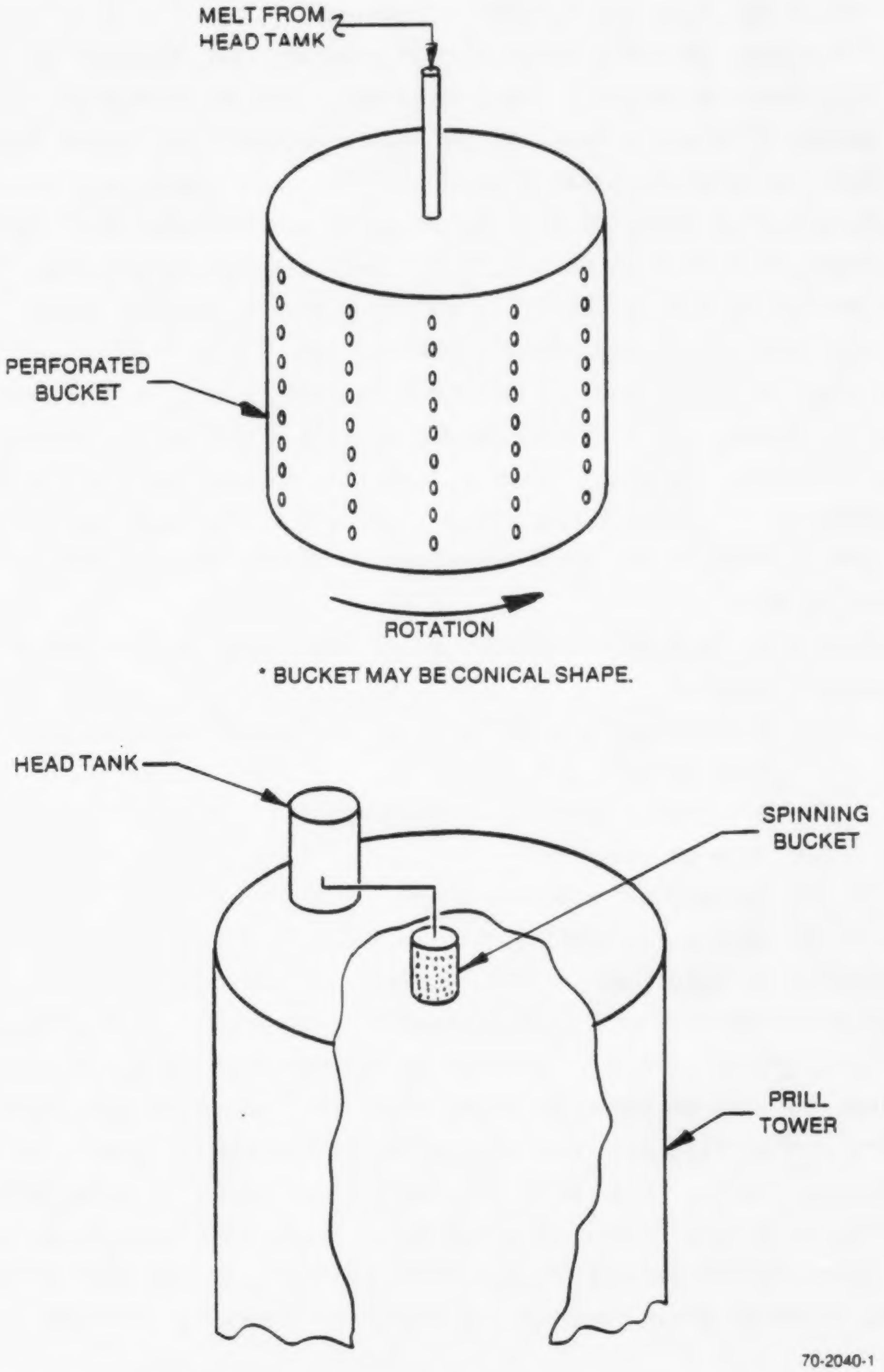


Figure 3-7. Spinning bucket.

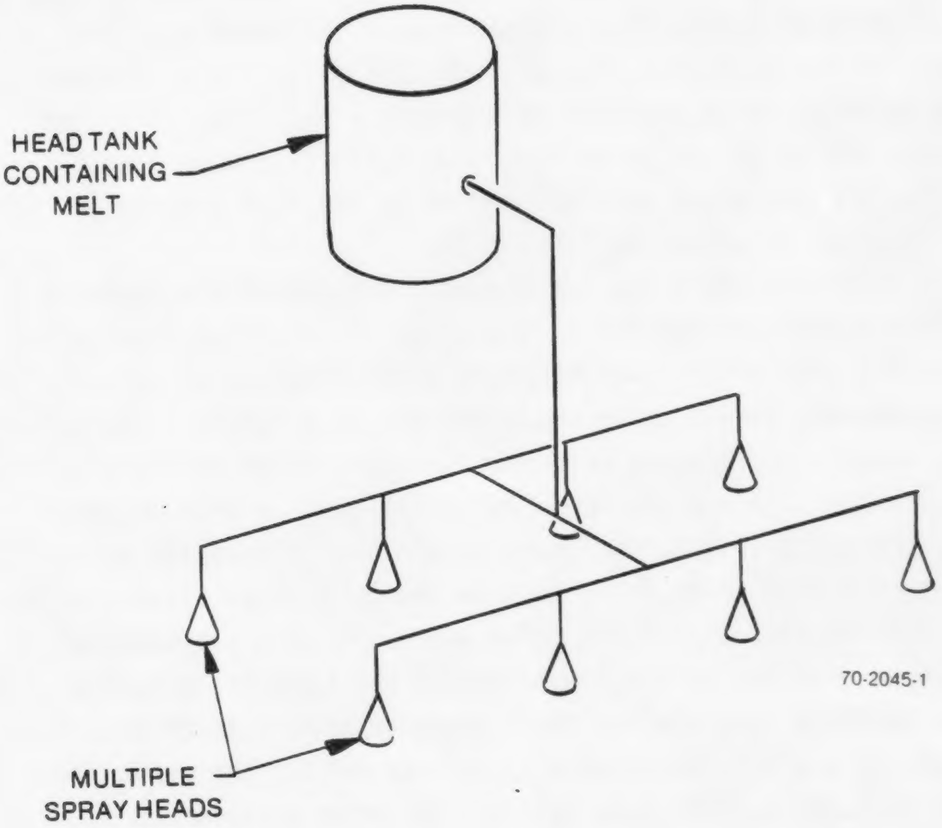
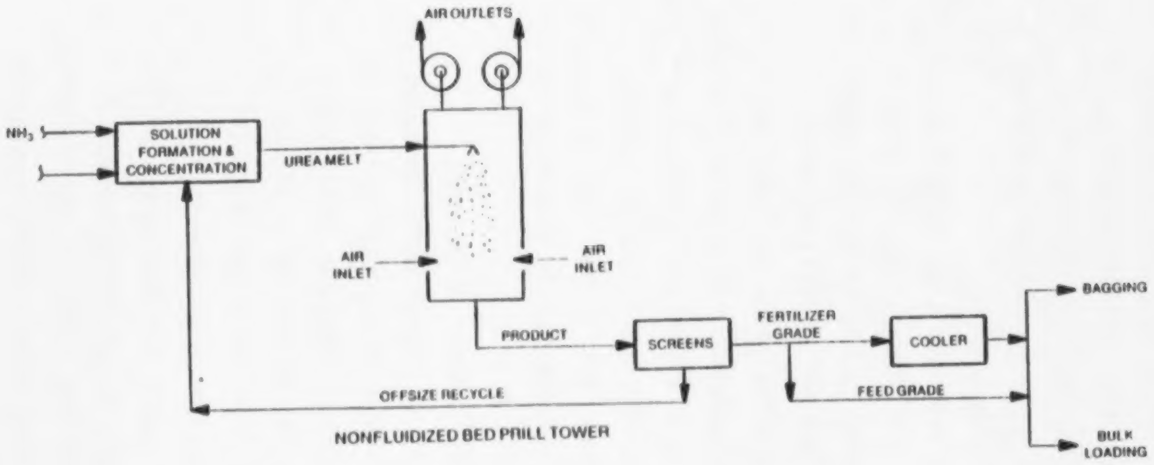


Figure 3-8. Multiple spray head arrangement.

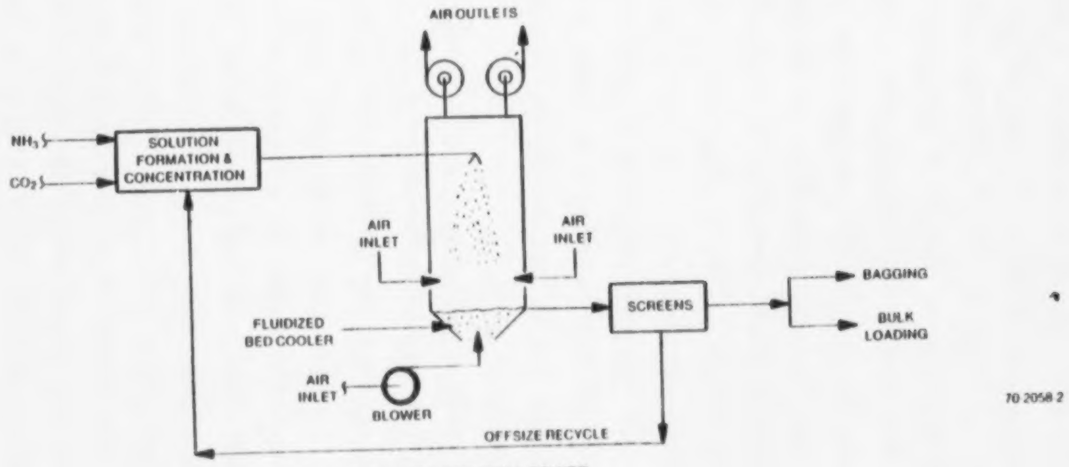
from feed grade prill towers, the total mass emissions per unit of feed grade prill production may be lower because of the lower airflows.[17]

Two different types of towers may be used to produce prills: fluidized and nonfluidized bed (see Figure 3-9). Fluidized bed prill towers incorporate a fluid bed cooler at the bottom of the prill tower, which provides additional cooling of agricultural grade prills without using an auxiliary rotary drum cooler. Higher airflow rates are used to suspend (fluidize) the prill bed and to provide supplementary cooling. The advantage of having a fluidized bed cooler at the bottom of tower is that the purchase of an additional large piece of equipment (a rotary drum cooler) is not necessary. The disadvantages of this type of tower are: (1) a large blower is required to suspend the prills at the bottom of the tower; and (2) if the tower is also designed to produce feed grade prills, the additional cooling provided by the fluidized bed is more than required for proper solidification.[18]

Nonfluidized bed towers may use an additional rotary drum cooler to provide the necessary cooling during production of agricultural grade prills. Alternately, prill tower height or prill tower air velocity could be increased. Prills collected at the bottom of nonfluidized bed towers are raked onto conveying belts for transport to the rotary drum cooler or storage. If a nonfluidized bed prill tower is also designed to produce feed grade prills, the rotary drum cooler is bypassed during the production of feed grade prills because the prill tower alone supplies sufficient cooling (see Figure 3-9). The advantages of a nonfluidized bed prill tower are: (1) airflow rates through the tower are generally lower than through a fluidized bed prill tower by as much as 20 percent (see Appendix A) and thus entrainment is reduced and (2) the cooler can be bypassed when making feed grade prills. The major disadvantage is that the production of agricultural grade prills usually requires the addition of a rotary drum cooler.



NONFLUIDIZED BED PRILL TOWER



FLUIDIZED BED PRILL TOWER

Figure 3-9. Process flow diagram for prill tower.

Ambient air conditions can affect prill tower emissions. The ambient air temperature determines the required airflow rate through the tower. Theoretically, the required winter airflow rate is approximately 60 percent of that needed during summer operation. Ambient humidity can also affect prill tower emissions. If humidity is high, airflow rates must be adjusted. Higher airflow rates, in general, result in higher emissions, as noted for fluidized bed prill towers.

Data supplied by industry indicates the particle size distribution of prill tower emissions is affected by ambient temperature.[19] It appears that as the falling molten urea droplet is cooled by the tower airflow, urea is vaporized from the surface of the solidifying prill. This urea vapor then condenses in the cold tower airflow to form small diameter particles. Therefore, during colder weather the size distribution shifts toward smaller particles. Although it is reported[19] that uncontrolled emissions are reduced under these conditions, the grain loading remains constant due to the reduction in tower airflow. Additional data concerning this shift and its affect on control device performance is presented in Section 4 of Chapter 4.

Melt spray conditions can also affect prill tower emissions. Theoretically, higher melt temperatures result in higher emission rates due to the increase in surface vapor pressure and associated increase in fuming.[20] In addition, an increase in melt spray pressure could result in higher emissions due to increased atomization of the spray stream.

Uncontrolled particulate emission rates from fluidized bed prill towers are higher than those from nonfluidized bed prill towers for agricultural grade prills, and approximately equal for feed grade prills. Emission testing was conducted by EPA on a new, large fluidized bed prill tower facility during the production of feed grade and agricultural grade prills. Airflow rates during testing were within normal operating limits and the melt temperature to the sprayheads did not vary more than 3K (6°F). EPA emission testing on a nonfluidized bed tower was conducted during agricultural grade production only. The nonfluidized bed prill tower tested was an older tower designed for lower production capacities.

Particulate emissions as measured during EPA testing from a fluidized bed tower producing feed grade prills were 1.80 kg/Mg (3.60 lb/ton) of product. Particulate emissions measured during EPA testing during the production of agricultural grade prills were 3.12 kg/Mg (6.23 lb/ton) of product from a fluidized bed prill tower and 1.90 kg/Mg (3.80 lb/ton) of product from a nonfluidized bed prill tower. Table 3-3 presents data for tests of uncontrolled emissions from nonfluidized bed prill towers. Industry test data shows that uncontrolled emissions from a nonfluidized prill tower are slightly greater (13 percent) during feed grade production than uncontrolled emissions during agricultural grade production. However, due to differences in test methods and difficulties involved in measuring emissions from prill towers (see Chapter 5), this data may be misleading. Particulate emissions for a nonfluidized bed prill tower producing feed grade prills have not been tested by EPA.

3.2.4 Granulation

Granulation has become the more popular means of producing solid urea for fertilizer uses. There are two methods currently being used to produce urea granules: drum granulation and pan granulation. Each of these processes are described in the following sections.

3.2.4.1 Drum Granulation. With one exception, all drum granulators operating in the United States are manufactured by one company and are essentially similar in design and operation. Presently, 18 of these granulators operate at five different urea plants in the United States. The production rate of each granulator is approximately 363 Mg/day (400 tons/day). The one exception is a larger drum granulator designed to produce 773 Mg/day (850 tons/day).

The drum granulator (see Figure 3-10) consists of a rotating horizontal cylinder about 4.3m (14 ft) in diameter divided by a retaining dam into two sections, the granulating section and the cooling section. Both sections have lifting flights welded to the wall. A pipe running axially near the center of the granulating section emits a fine spray of liquid urea (including formaldehyde additive if used) in an upward direction. Seed urea particles are fed into the drum at the granulation end. As the drum rotates, the lifting flights pick up the urea seed

TABLE 3-3. UNCONTROLLED UREA PARTICULATE EMISSION TESTS FOR NONFLUIDIZED BED PRILL TOWERS[21]

Plant	Product Type	Capacity Mg/day (TPD)	Air Flow Nm^3/s (1000 DSCFM)	Grain Loading g/Nm^3 (gr/DSCFM)	Emission Rate g/s (lb/hr)	Emission Factor kg/Mg (lb/ton)	Temperature K (°F)	Percent Moisture in air	Data Source
F	AG	199.6 (219.6)	42.9 (90.9)	0.0822 (0.0359)	3.53 (28.0)	1.53 (3.06)	325 (126)		Industry
	FG	198.2 (218)	9.1 (19.2)	0.443 (0.1935)	4.02 (31.9)	1.76 (3.51)	367 (209)		Industry
G	AG	818.2 (900)	143.0 (303)	0.0295 (0.0129)	4.22 (33.5)	0.52 (1.04)	336 (145)	2.05	Industry
H	AG	236.4 (260)			2.86 (22.7)	1.05 (2.10)			Industry
I	AG	227.3 (250)			1.02 (8.13)	0.39 (0.78)			Industry
J	AG	500 (550)	85.0 (180)	0.0456 (0.0199)	3.87 (30.71)	0.67 (1.34)	312 (102)	1.18	Industry
K	FG	218.2 (240)			4.05 (32.18)	1.61 (3.22)			Industry
C	AG	345 (380)	51 (108)	0.0544 (0.0238)	2.77 (22.0)	0.70 (1.39)	308 (95)	1.84	Industry
L	AG	409 (450)	122.7 (260)	0.0689 (0.0301)	8.44 (67.1)	1.79 (3.58)			Industry
E	AG	264.8 (291.3)	38.2 (80.9)	0.1522 (0.0665)	5.81 (46.1)	1.9 (3.8)	311 (101)	1.07	EPA

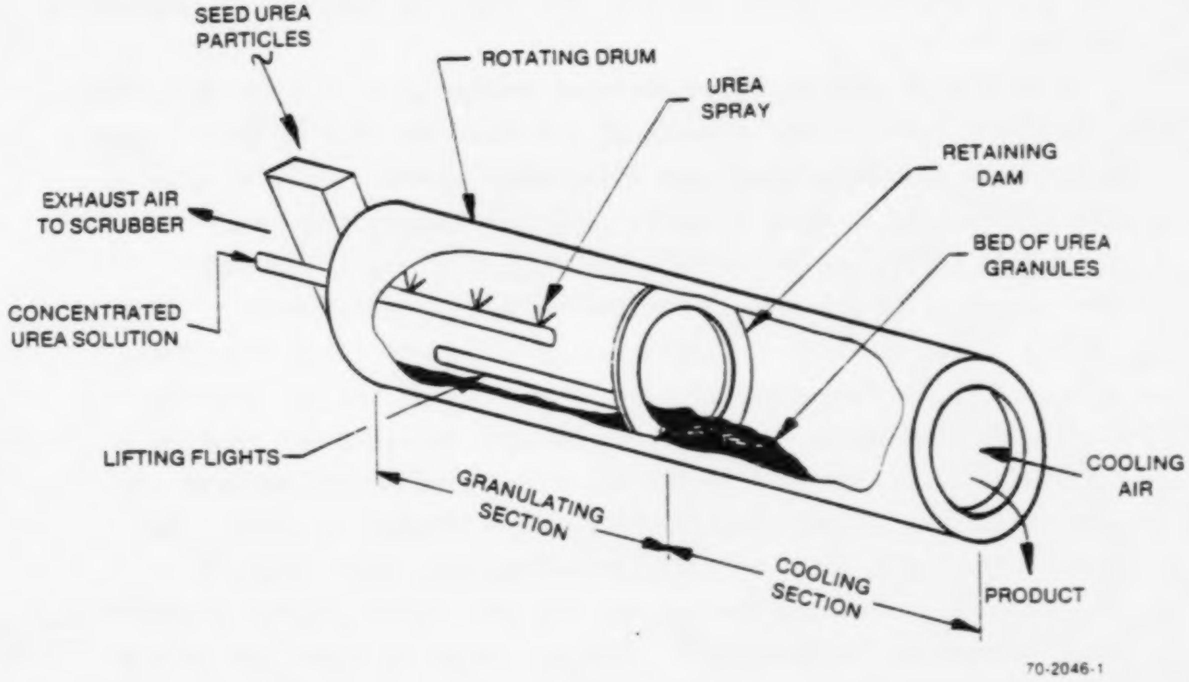


Figure 3-10. Drum granulator.[22]

particles and shower these particles down through the urea spray. As the particles fall and roll, they become coated with molten urea. Particles gradually build up to product size by addition of successive layers of liquid, which solidify to give the granule an onion-skin-like (concentrically layered) structure.

Particles in the granule bed will tend to segregate according to size, the smaller granules of urea settle to the bottom to be picked up by the lifting flights. The drum operates at a slight angle and material migrates by gravity towards the cooling section. Larger particles at the top of the granule bed pass over the retaining dam into the cooling section.

Throughout this operation granules are cooled with a countercurrent flow of air. An airflow velocity of 1.2 meter/sec (4.0 ft/sec) is used to minimize seed entrainment and disturbance of the fine melt spray. The cooling air, at this velocity, is chilled to an inlet temperature of about 283K (50°F) and has an exit temperature of about 358K (185°F).[24,25] Urea spray in the granulating section is held at approximately 413K (285°F),[26] but granules exiting the cooling section are approximately 310K (104°F).[27] Cooled granules (Figure 3-11) are removed from the cooling section and undersized particles are separated and recycled as seed material. Oversize granules are either crushed and recycled as seed, dissolved and returned to the solution process, or both. The typical recycle to product ratio for a drum granulator is 2:1.[28]

Cooling air passing through the drum granulator entrains approximately 10-20 percent of the product.[29] This air stream is controlled with a wet scrubber which is standard process equipment on all drum granulators.

Emission rates from drum granulators may be affected by the following parameters:[31]

1. Number, Design and Location of lifting flights
2. Airflow rates through the drum
3. Melt spray pressure
4. Dam height

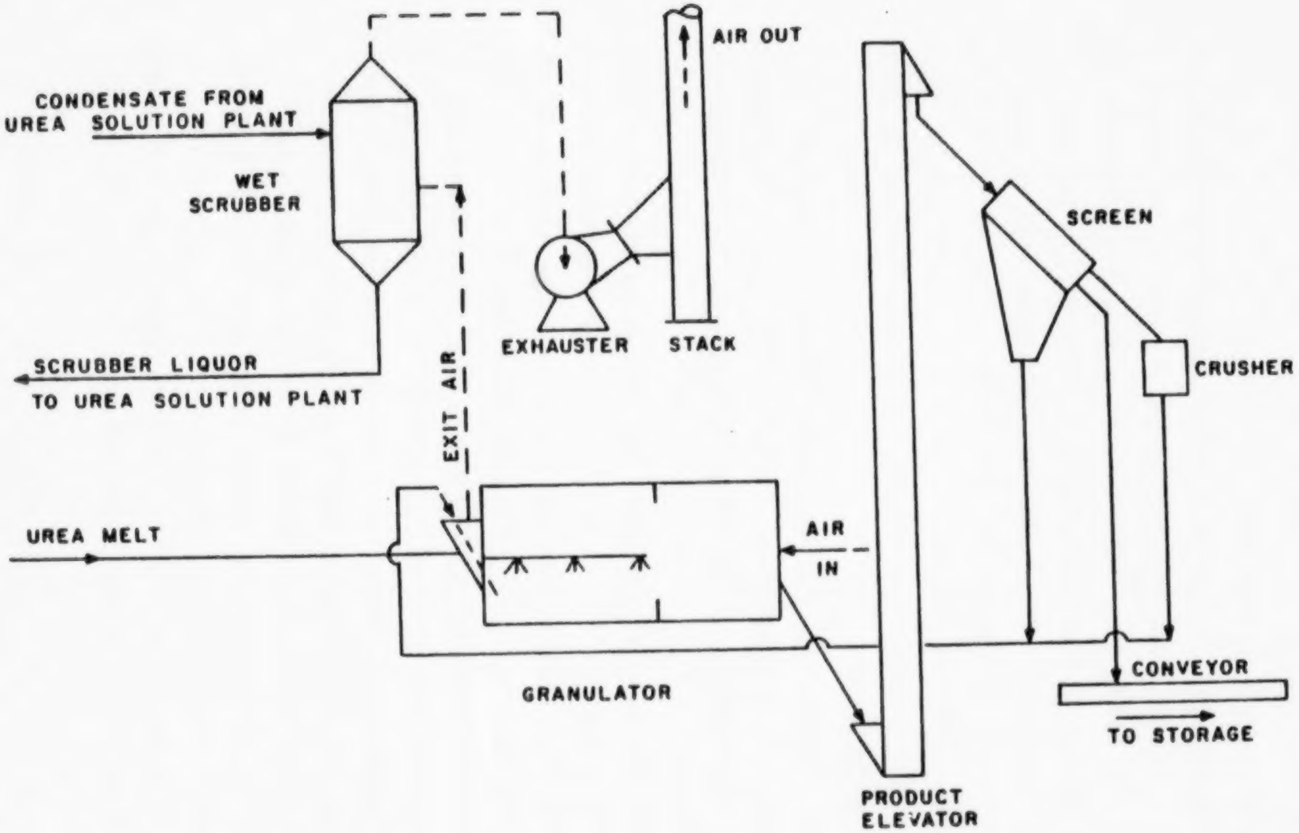


Figure 3-11. Urea drum granulation process.[30]

5. Bed temperature
6. Recycle rate of seed material
7. Product size.
8. Rotation rate of the drum

The number, design and location of lifting flights directly affect the emission rate. Flights lift and drop granules through the moving air stream to cool the particles. When flights are located close to the air exit of the granulator, fine particles are entrained in the air stream leaving the granulator. Modifications have been made to many existing drum granulators to change the size and/or shape of the lifting flights, and to remove lifting flights at the air discharge end of the granulator because of excessive entrainment. This modification is also being made on new installations.[32]

Air velocities through the drum have been reported as high as 1.8 meters/sec (7 ft/sec).[33] A greater air velocity will result in increased entrainment of small particles in the drum granulator and a subsequent increase in emissions.

The pressure of the melt at the spray nozzles is maintained within a range of about 2.5 - 3.8 kPa (10-15 psig).[34] Lower pressures cause the granules to take the shape of popcorn and higher pressures cause an increase in fine granules, which may increase emissions.[35]

The dam at the center of the granulator is used to separate the granulation zone and the cooling zone. Changing its height will result in changes in bed temperature, which could affect emission rates. The dam height is set by the manufacturer and is not normally changed.

The bed temperature in the granulation zone is reported to be critical.[36] Only a relatively narrow temperature range can be tolerated. If the bed temperature drops too low, the granules will agglomerate. If the bed temperature is increased significantly and maintained for several hours, the bed will turn to dust and emissions will increase.[38]

The recycle rate of seed material affects the bed temperature and therefore the emission rate. An increase in seed material recycle rate will cool the bed, while a decrease will raise the bed temperature.[38] As mentioned previously, increased bed temperature results in increased particulate emissions.

Drum granulators have an advantage over prill towers in that they are capable of producing very large particles without difficulty. Granulators also require less air for operation than do prill towers. A major disadvantage of granulators is their inability to produce the smaller feed grade granules economically. To produce smaller granules, the drum must be operated at a higher seed particle recycle rate. It has been reported that although the increase in seed material results in a lower bed temperature, the corresponding increase in fines in the granulator causes a higher emission rate.[39]

Increasing the rotation rate of the drum may increase entrainment of urea in the airstream, with a corresponding increase in the loading of urea to the scrubber. However, once set by the manufacturer the rotation rate of the drum is not normally changed. The original granulator design of the granulators called for the drums to rotate at 9 rpm. But because of excessive wear, rotation rates have been decreased to 6 rpm, with no apparent effect on product quality.[40]

As previously stated, most granulators are a standard size and are operated in the same way with many of the parameters affecting emissions fixed by granulator design. Uncontrolled emissions from drum granulators were determined at two different plants. The average particulate emission rate from each of these tested facilities were 63.6 and 148.8 kg/Mg (127.2 and 297.6 lbs/ton) of product. The granulators tested were of the same design. Airflow rates, melt temperatures, and melt pressures were within normal operating limits during EPA testing.

3.2.4.2 Pan Granulation. The pan granulation process operates on the same principle as the drum granulator, forming granules by adding successive layers of molten urea to seed particles. The equipment, however, is quite different. It consists of a large, tilted rotating circular pan (see Figure 3-12). Seed material deposited near the top of the pan along with fine particles carried up by the rotating pan, fall through a fine spray of liquid urea. The newly sprayed particles drop to the bottom of the pan. As in the case of the drum granulator, smaller particles tend to sift down toward the bottom of the granule bed on the lower part of the pan. The larger granules spill over the edge of the pan onto a conveyor belt.

Pan granulation is a fairly recent development in urea processing and has yet to gain widespread use. It is still in the pilot plant stage with only one existing pan granulator in operation in the U.S. (see Figure 3-13). The pan granulator yields a product which is less spherical than either drum granules or prills and not quite as hard as a granule produced by a drum granulator.[41] Pan granulation also tends to have a larger recycle to product ratio, as most of the required cooling in the pan is accomplished through heat absortion by the cooled recycle seed material. This mode of cooling is necessary since the air flowrate is only 20 percent of a drum granulator's air flowrate.[42,43]

The pan granulator operates with an optimum bed temperature between 377K and 380K (220°F to 225°F).[44] The temperature of recycled seed material is approximately 343K (158°F).[45] The urea solution (99.0 percent urea) is kept at approximately 413K (285°F) to assure even coating of particles before crystallization occurs.[46] The recycle to product ratio will generally fall between 2:1 and 3:1.[47]

The recycled material serves to cool the granule bed and maintains the desired bed temperature. A decrease in recycle ratio will result in an increase in bed temperature.

The pan granulator is followed by two rotary drum coolers. All of the material leaving the first cooler is screened. The oversized stream is either redissolved and returned to the solution concentration steps, or crushed and returned to the pan with the undersized material. The amount of crushed material used as seed is held to a minimum, as use of this material leads to the formation of agglomerates and weak granules. This recycle stream to the pan contributes to the cooling of the bed

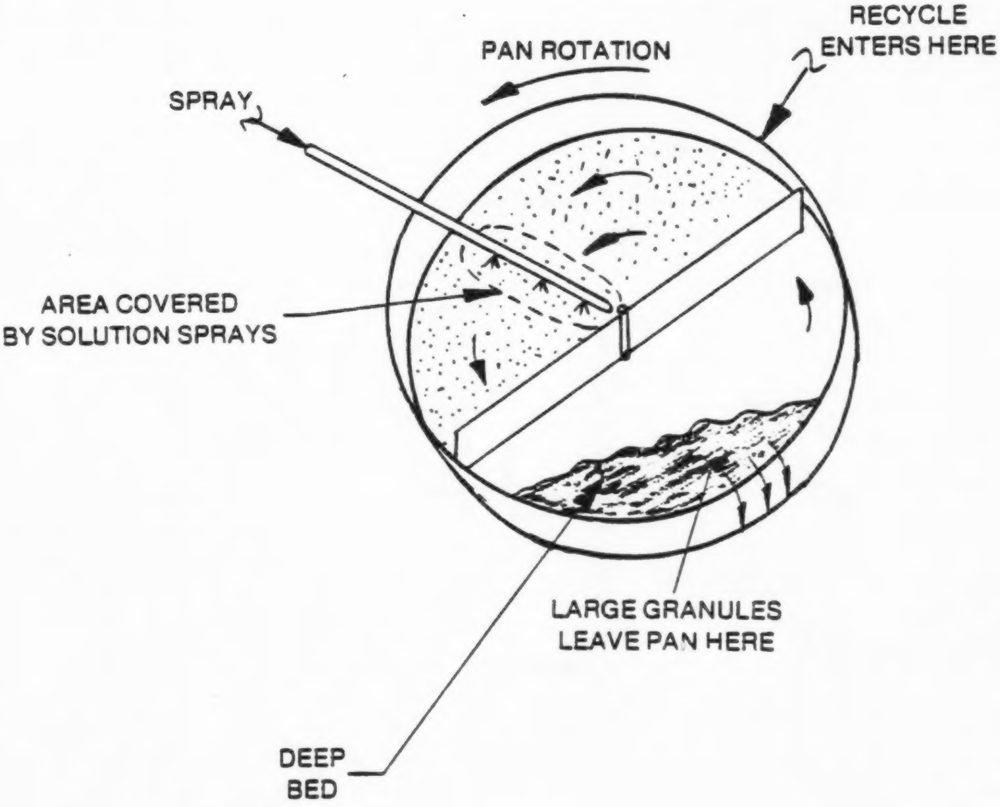

RECYCLE ENTERS HERE
PAN ROTATION
SPRAY
AREA COVERED BY SOLUTION SPRAYS
LARGE GRANULES LEAVE PAN HERE
DEEP BED

Figure 3-12. Pan granulator.

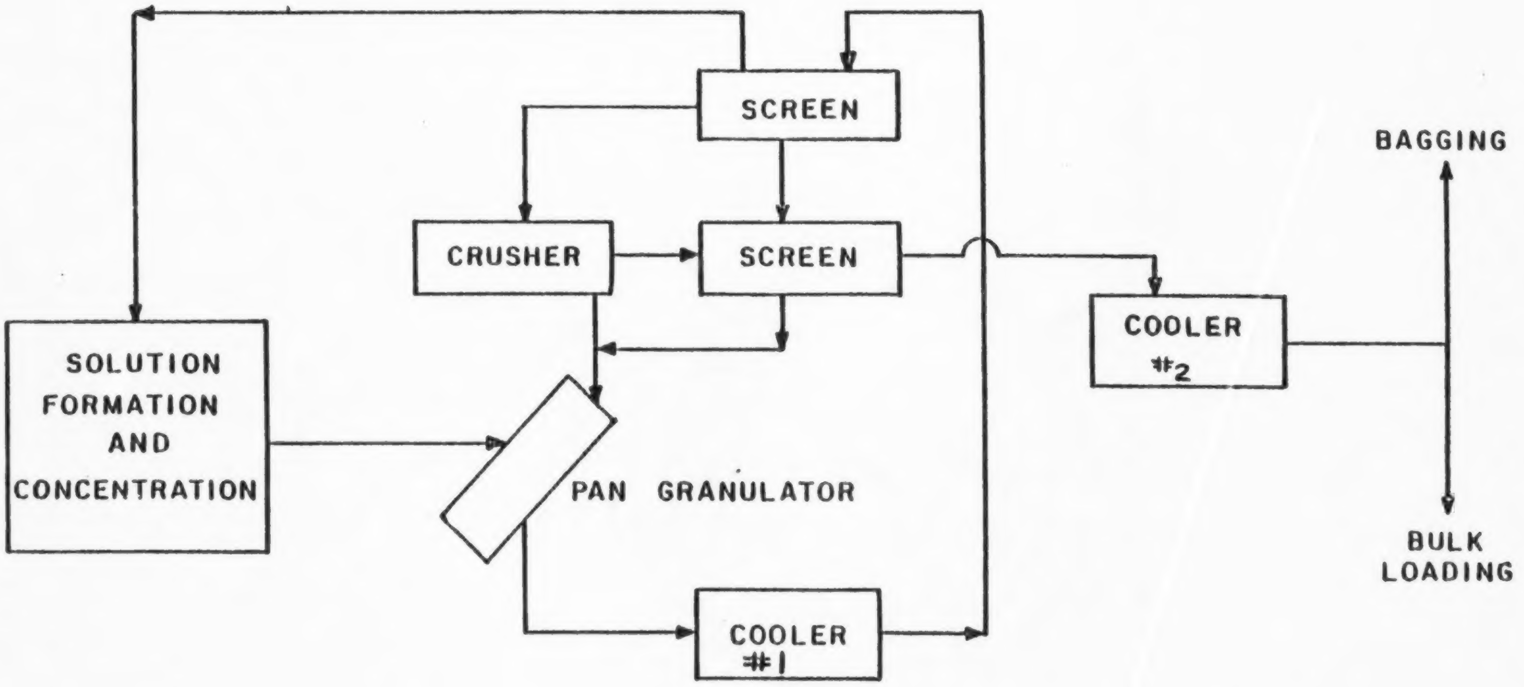


Figure 3-13. Process flow diagram for pan granulator.

particles as noted previously. Product size urea is sent to the second cooler and then conveyed to the warehouse for shipment.

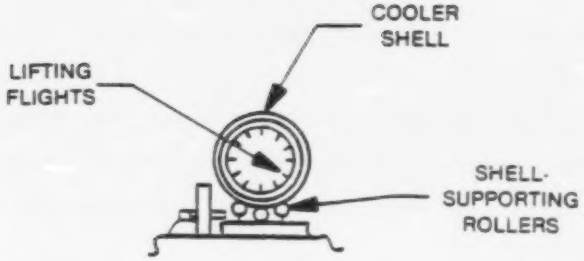
The advantage of the pan granulator over the drum granulator is that the airflow rate required for cooling is approximately one fifth of that required for the drum granulator. Although the existing plant (which is still experimental) uses two coolers, a new plant could be designed with only one cooler thus reducing the total system airflow needed for cooling.[48]

Test data on the pan granulator cannot be directly correlated to EPA test data because of differences in test methods. However, uncontrolled particulate emissions were reported to be approximately 2.1 kg/Mg (4.2 lb/ton) of product.[49]

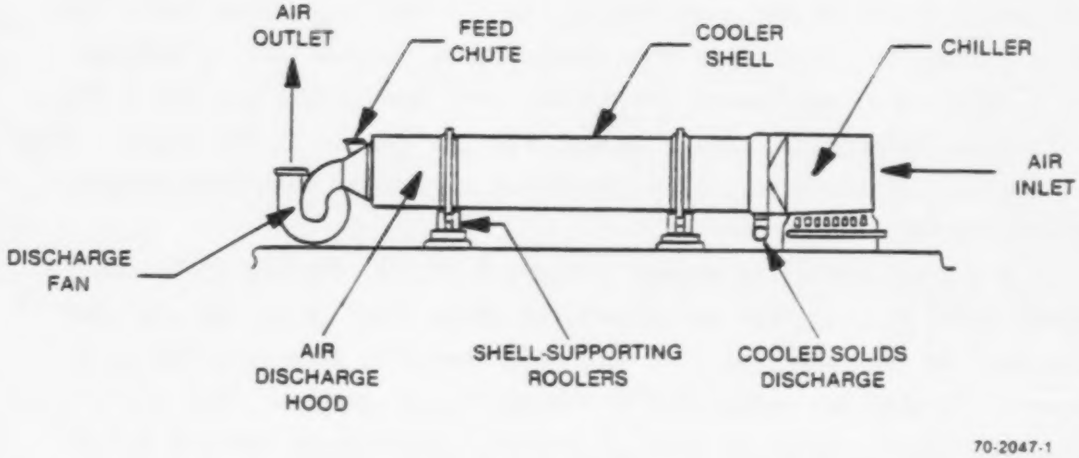
3.2.5 Solids Cooling

Supplementary cooling for the pan granulation process and for agricultural grade prills produced in nonfluidzed bed prill towers is provided by auxiliary coolers (see Figures 3-5 and 3-13.). All coolers currently in use in the urea industry are of the rotary drum type. The rotary drum cooler consists of a revolving cylindrical shell, horizontal or slightly inclined toward the outlet. Hot feed enters one end of the cylinder; cooled material discharges from the other. As the shell rotates, internal flights lift the solids and shower them down through a countercurrent flow of air.

A typical cooler is shown in Figure 3-14. A rotating shell made of sheet steel is supported on two sets of rollers and driven by gear and pinion. At the upper end is a hood which connects through a fan to a stack. Flights are welded inside the shell. At the lower end the cooled product discharges onto a conveyor. Just beyond the end of the rotary cooler is a set of chillers which cools the incoming air. The air is moved through the cooler by an induced draft fan which keeps the system under a slight vacuum. Emissions from coolers consist of urea particles that become entrained in the rotary cooler air stream.



END VIEW



SIDE VIEW

Figure 3-14. Typical countercurrent direct-contact air chilled rotary cooler.

The following parameters affect emissions from rotary drum coolers:

(1) Number, design and location of lifting flights
(2) Air flowrate through the drum
(3) Bed temperature
(4) Speed of drum rotation

Rotary drum coolers operate in much the same manner as the cooling section of drum granulators. Therefore, parameters will affect emissions in similar ways. The number, design, and location of lifting flights affect the amount of fine particles entrained in the cooling airstream. Likewise, the rotational speed of the drum may affect the entrainment of urea in the airstream.

The airflow rate through the drum affects emissions from rotary drum coolers. Increased airflow rates increase the amount of fines entrained in the airstream. Also, with increased air flows, larger particles may be transported in the cooling air. The bed temperature in the rotary drum cooler can affect emissions indirectly. Higher bed temperatures require increased airflow rates in order to cool the prills. And, as discussed above, increased air flowrates cause higher emission rates.

Testing of a rotary drum cooler cooling agricultural grade prills was performed by EPA at one facility. Results of this test indicate an uncontrolled emission rate of 3.90 kg/Mg (7.80 lb/ton) of product. The cooler tested was of typical capacity for urea coolers. Airflow rates during testing varied within normal operating limits.

3.2.6 Solids Screening

Solid urea is screened to remove offsize product. The offsize material may be returned to the process in the solid phase, as is typically done in granulation plants, or it may be redissolved in water and returned to the solution formation end for reprocessing. This second option is usually performed at urea prilling facilities.

Product specifications for the more typical grades and types of urea are presented below.[50,51,52]

Feed Grade

100 percent through a 10 mesh screen (U. S. Sieve)
90 percent caught on a 40 mesh screen (U. S. Sieve)

Agricultural Grade

98 percent through a 5 mesh screen (U. S. Sieve)
98 percent caught on a 30 mesh screen (U. S. Sieve)

Granular Grade

99 percent through a 6 mesh screen (U. S. Sieve)
99 percent caught on a 20 mesh screen (U. S. Sieve)

Several types of screens are employed to separate product size from oversize and undersize material. Screening equipment commonly used in the urea manufacturing industry include shaking screens and vibrating screens.

Dust is generated due to abrasion of urea particles and the vibration of the screening mechanisms. Therefore, almost all screening operations used in the urea manufacturing industry are enclosed or have a cover over the uppermost screen. Uncontrolled emissions from solids screening were not tested by EPA. Results of survey inspections conducted during this program indicated that this operation is a small emission source and in most cases no visible emissions were observed.[53,54,55] Therefore, particulate emissions from solids screening will not be considered further in this report.

3.2.7 Coating Operations/Additives

Clay coatings are used in the urea industry to reduce product caking and urea dust formation. However, clay coatings also reduce the nitrogen content of the product and the coating operation itself creates of clay dust emissions. Presently, only three plants are still using coatings.[56] The popularity of coating has diminished considerably because of the increasingly common practice of injecting additives into the liquid or molten urea prior to solids formation.[57,58] Additives reduce solids caking during storage and urea dust formation during transport and/or handling. Additives react with the urea to form a crystalline urea compound by a mechanism that is not clearly understood.[59]

The resulting solid particle is harder than solids made without additives. Additives, therefore, have replaced coatings in a major portion of the urea industry, and this trend is expected to continue.[60]

The most common additive is formaldehyde which is incorporated into the liquid urea before solid formation.[61,62] The formaldehyde content of the finished urea will generally fall between 0.3 and 1.0 percent.[63.64] Because addition of the additive involves a simple injection into the urea melt, no particulate emissions result from the process. Formaldehyde emissions from EPA testing are reported in Table 3-1 and Appendix A.

Emissions attributable to coating include entrained clay dust from loading, in-plant transfer, and from leaks around the seals of the coater. No emissions data are available to quantify this fugitive dust source. For this reason, coaters will not be considered further in this document.

3.2.8 Bagging and/or Bulk Shipping

Solid urea product is either bagged or bulk shipped. The majority of product is bulk shipped; approximately 10 percent is bagged. Two types of bags are used: the open-top, sewn bag and the corner-fill, valve-type bag. The open-top bag is held under the bagging machine which fills the bag to a predetermined weight. After filling, the top is pinched together and sewn. The corner-fill valve bag is "factory closed"; that is, the top and bottom are partially closed either by sewing or by pasting, and a small single opening or valve is left on one corner. Urea is discharged into the bag through the valve. The valve closes automatically due to the back pressure produced by the contents of the bag as soon as it is filled.

Bagging operations are a source of particulate emissions. Dust is emitted from each bagging method during the final stages of filling when dust-laden air is displaced from the bag by urea. Bagging operations are conducted inside warehouses and are usually vented to keep dust out of the workroom area according to OSHA regulations.

Mass emission tests were not conducted by EPA on an uncontrolled bagging operation. However, data provided by industry indicates that uncontrolled particulate emissions are approximately 0.095 kg/Mg (0.19 lb/ton) of product bagged. This emission rate was determined by weighing the amount of urea collected in a baghouse used to control the bagging operation.[65]

On a national basis only a small fraction of urea produced is bagged (approximately 10 percent).[66] The major portion is bulk loaded in trucks or enclosed railroad cars. The actual method of product bulk loading varies from plant to plant. During bulk loading, long flexible chutes are used to convey the urea from the storage hopper to the tank truck or railroad car.

Very few plants control their bulk loading operations. As discussed above, emissions vary with use of coatings. During this study, bulk loading of a coated urea product was not observed; however, the bulk loading of uncoated urea was observed. Generation of visible fugitive particulates was very slight.[67]

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4.0 EMISSION CONTROL TECHNIQUES

This chapter discusses techniques used for controlling urea particulate emissions from prill towers, coolers, granulators, and bagging operations in the urea industry.

As mentioned in Chapter 3, ammonia and formaldehyde emissions are also generated in urea processes. However, the major objective of this study is to evaluate particulate emissions. Accordingly, this chapter concentrates on the effectiveness of various devices in controlling particulate matter.

The majority of the data used in assessing control device effectiveness was generated by an EPA source testing program conducted in conjunction with this project. Testing involved particulate emission measurements at five urea plants utilizing test methods similar to the test method in Appendix B. Appendix A provides more detailed information on all test data used in this chapter.

The chapter is organized in the following manner. Section 4.1 presents a general overview of control techniques used in the urea industry. Section 4.2 describes several of these control techniques in greater detail and outlines the factors that affect their performance. Section 4.3 reviews available industry and EPA emission test data. Finally, Section 4.4 evaluates this data and control device performance.

4.1 OVERVIEW OF CONTROL TECHNIQUES

With the exception of bagging operations, urea emission sources are typically controlled with wet scrubbers. The preference toward scrubber systems as opposed to dry collection systems is primarily due to the ease of recycling dissolved urea collected in the device. Scrubber liquors are recycled back to the solution concentration process, eliminating potential waste disposal problems and recovering the urea collected.

Concerning other potential control devices, fabric filters are not suitable for controlling emissions from many sources because the hygroscopic nature of urea particulate combined with the moisture content of the gas streams could cause blinding of the bags. Dry cyclones offer lower collection efficiencies than scrubbers in urea particulate applications. Electrostatic precipitators are not currently in use in any urea industry applications.

Fabric filters (baghouses) are used in the control of fugitive dust generated in bagging operations where humidities are lower and blinding is not a problem. Many bagging operations are uncontrolled. However, if a control device is used, baghouses are the typical method of control.

Table 4-1 presents a summary of the present population of control devices being applied to prill towers, granulators, and coolers. As mentioned previously, these sources use wet scrubbers if a control device is used. The following subsections provide a brief description of how controls are applied to each urea emission source under consideration.

4.1.1 Nonfluidized Bed Prill Tower Controls

The majority of nonfluidized bed prill towers are uncontrolled. Of the seven prill towers which utilize control devices, one uses a spray tower scrubber, two use packed bed scrubbers, one uses a wetted fibrous filter, and three companies consider the type of scrubber used to be confidential information.

Control devices vary considerably in the number used and in placement for various applications. The most common location for scrubber mounting on nonfluidized bed prill towers is on the top of the tower. Only two installations duct emissions to ground level.[1,2] Tower mounting is usually more economical since long runs of corrosion resistant ducting are not required. However, scrubbers mounted on top of towers typically do not have the extended stacks necessary for suitable sampling locations. In addition, tower mounting may require a strengthened prill tower in order to withstand the additional weight and wind load of the scrubber.

TABLE 4-1. SUMMARY OF USE OF WET SCRUBBERS IN THE UREA INDUSTRY[46,47,48]

Emission Source	No. of Emission Sources	Type of Scrubber								
		Spray Tower	Packed Tower	Mechanically Aided	Wet Cyclone	Tray Type	Entrainment	Fibrous Filter	Scrubber Type Unknown	Uncontrolled
Prill Towers										
NFB	15	1	2	0	0	0	0	1	3	8
FB	3	1	0	0	0	0	1	0	1	0
Rotary Granulators	19	0	1	0	0	0	18	0	0	0
Pan Granulator	1	0	0	0	1	0	0	0	0	0
Coolers	6	0	2	2	0	1	0	0	0	1

The number of scrubbers used on a nonfluidized bed prill tower varies considerably. One system uses a single device, while other prill towers use up to four devices. The use of more than one scrubber allows for variability in airflow rates. A prill tower which produces both feed and agricultural grade product may need only 30 percent of the agricultural grade airflow during feed grade production. Seasonal changes in ambient temperatures may also dictate that flow rates be varied in order to maintain a reasonably constant prill temperature. Thus, a scrubber system needs the ability to be turned down to lower airflow rates while maintaining removal efficiencies. Multiple scrubbers allow units to be removed from service while maintaining normal airflow and pressure drops in the remaining operating scrubbers. The wetted fibrous filter allows pressure drop to be adjusted readily while the unit is in operation, thus accomodating changes in airflow rates.

4.1.2 Fluidized Bed Prill Tower Controls

Three fluidized bed prill towers are currently operating and all use some type of scrubber system. One manufacturer considers all information concerning their in-house designed scrubber system proprietary. Another manufacturer uses a spray tower scrubber with extensive internal baffles. The third fluidized bed prill tower uses multiple entrainment scrubbers. All fluidized bed prill towers use tower mounted control devices. As with nonfluidized bed prill towers, this mounting typically causes problems in prill tower emission testing.

4.1.3 Granulator Controls

With one exception, all rotary drum granulators are controlled by nearly identical entrainment scrubbers. These are essentially the same scrubbers as used on the fluidized bed prill tower mentioned previously; however, a higher pressure drop is used for granulator applications. The only exception to the use of entrainment scrubbers is the use of a packed tower at one drum granulator installation. This drum granulator is produced by a different company than the other 18 granulators.

Since nearly all drum granulators are similar designs marketed by the same company, installations are fairly standard. One scrubber is used for each granulator and a testable outlet stack is typically provided. However, at least one installation uses a common outlet stack for two scrubbers.[3]

The single pan granulator operating in the United States uses a wet cyclone scrubber.

4.1.4 Rotary Drum Cooler Controls

Rotary drum coolers are used to cool agricultural grade prills when sufficient cooling is not provided in the prill tower. Coolers are not required in fluidized bed prill towers, during feed grade production, or when adequate cooling airflow is available in the prill tower.

A wide variety of control devices are currently used to control cooler exhausts: packed towers (both moving bed and conventional bed), mechanically aided scrubbers and tray towers. One cooler is uncontrolled.

4.1.5 Bagging Operation Controls

At some urea plants, a portion of the solid product is bagged, as discussed in Chapter 3. Bagging operations are hooded and vented to the atmosphere to reduce dust levels in the workroom air, in accordance with Occupational Safety and Health Administration (OSHA) standards.

Emissions from the exhaust ventilation system for the bagging operation may be vented directly to the atmosphere or through an air pollution control device. The most commonly used control device for bagging operations is a fabric filter (baghouse). Of the eleven urea plants conducting bagging operations, six use baghouses while one is reported to use a dry cyclone.[4] The remainder are uncontrolled.

4.2 DESCRIPTION OF CONTROL TECHNIQUES

In this section, the various types of control devices used in the urea industry are reviewed. This review includes a description of the device, the collection mechanism, and the factors that affect performance.

4.2.1 Wet Scrubbers

A wet scrubber is a device in which a gas stream is brought into contact with a liquid, usually water. Any device which introduces a liquid to clean an airstream may be termed a scrubber. Scrubbers are widely used to remove gaseous components as well as particulate matter.

Scrubbers rely on a variety of collection mechanisms, however, the dominant mechanisms in all scrubbers used in the urea industry are impaction and interception. The scrubber provides water droplets and/or wetted surfaces which impact and intercept the particles. The particulate laden liquid is then separated from the gas stream and recycled or discharged as waste.

Other collection mechanisms which may contribute to scrubber effectiveness include gravitational settling, diffusion (brownian motion), and condensation effects. However, the importance of these mechanisms are usually secondary in the types of scrubbers described in this chapter.

Scrubber performance depends on the characteristics of the dust laden airstream being cleaned and on the design and operation of the scrubber. The most important airstream characteristics are particle size distribution and grain loading. Other factors being equal, larger particles are removed with greater efficiency than smaller ones. Likewise, higher grain loadings may lead to agglomeration, enhancing scrubber effectiveness.

Two factors in the design and operation of a scrubber which may strongly influence performance are energy input and liquid flow rate. Increased energy input to the scrubber causes more turbulent gas-liquid contact and greater particulate removal. Similarily, increasing liquid flowrate in the scrubber usually enhances gas-liquid contact. In both factors, however, a level is reached where increases are no longer justified by the improvement in performance.

The high velocity, turbulent flow of gas through the scrubber causes a decrease in the gas phase pressure head. This pressure drop across the scrubber is a convenient means of measuring the energy used in the scrubber. High pressure liquid sprays may also supply energy, however, the importance of this energy input is usually secondary for scrubbers used in the urea industry.

4.2.1.1. Spray Tower Scrubbers. Figure 4-1 depicts a spray tower scrubber system of the type presently being used to control a fluidized bed prill tower. The airflow from the prill tower travels upward impinging on a baffle plate. As the gas flows around the baffle, several gas vortices are formed which increase the residence time in the scrubber. The gas stream passes through a jet of fine sprays which impacts the particles. Particle laden droplets fall to the bottom of the scrubber housing and are removed with the liquid stream.

In general, the performance of spray towers is influenced by the surface area of the scrubbing droplets and the relative velocity between the droplets and the particles entrained in the gas stream. Small droplets can enhance performance since small droplets provide a large surface for particle impingement. On the other hand, large droplets can also enhance performance since large droplets fall at high terminal velocities, and thus provide a high relative velocity between particles and droplets. This high relative velocity usually increases the chances of a particle impacting a droplet.

Depending on the particle size distribution of the incoming gas stream, an optimum droplet size which balances these two effects will provide best performance. This optimum size is reported to be in the range of 500 to 1000 microns over a wide range of particle sizes.[8] Droplet size is influenced by the nozzle configuration and the nozzle pressure. Nozzle pressures of 138 - 689 kPa (20 - 100 psig) are typical[9]; however, high pressure sprays of 2760 kPa (400 psig) may also be used when a very fine droplet size is desired.[10] Concerning liquid use in spray towers, a range of .0669 - 1.07 liters/m^3 of gas (.5 - 8 gal/1000 ft^3)[11] has been reported. Pressure drops in spray towers are usually very low, typically less than .5 kPa (2 in. W.G.).[12]

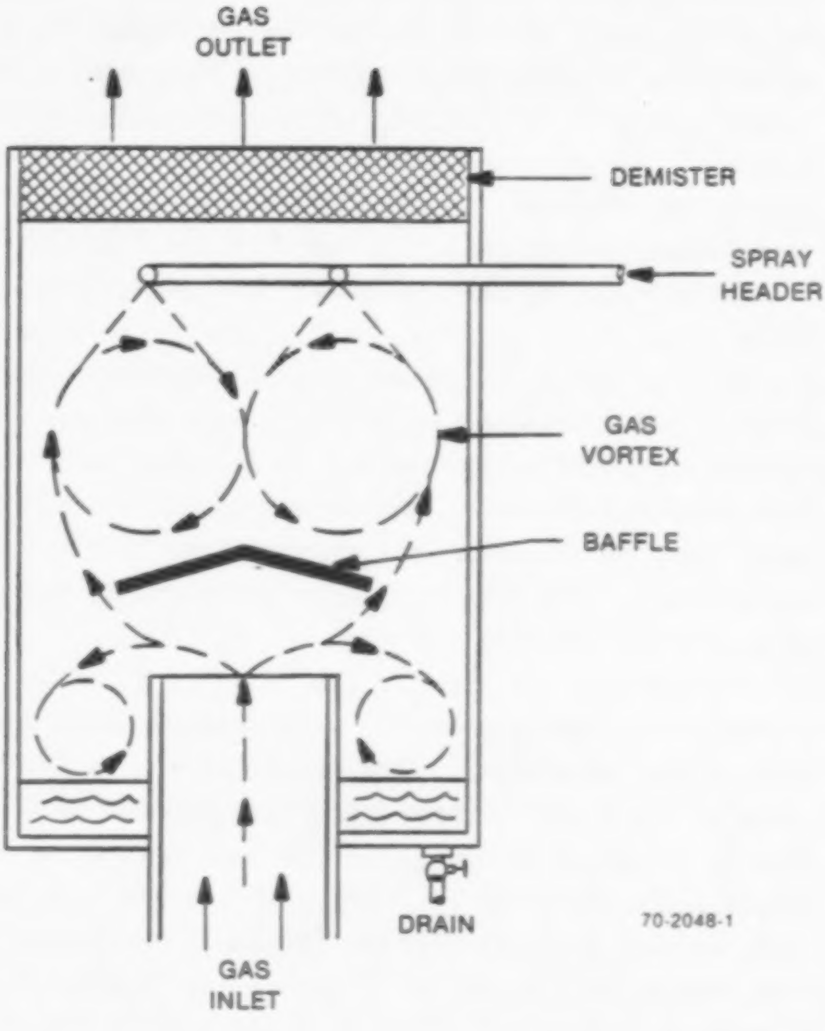

Figure 4-1. Typical spray tower scrubber.[49]

The spray tower currently used in urea prill tower applications is designed to operate at .25 - .5 kPa (1-2 in. W.G.) pressure drop with liquid to gas ratios of .134 - .268 liters/m^3 (1-2 gal/1000 ft^3). Spray nozzle pressure is 689 - 1380 kPa (100 - 200 psig).[13] Although efficiency curves for various particle sizes are not available, the manufacturer claims exit loadings of .0115 - .0344 g/m^3 (.005 - .015 gr/dscf) are achievable in urea prill tower applications.[14] Concerning visible emissions, the manufacturer has reported that opacities of 20 percent or less are achievable.[15]

4.2.1.2 Packed Towers. In packed towers (Figure 4-2) the scrubber interior is packed with shaped elements or materials such as crushed rock. The packing is irrigated by water sprays to keep the packing wet and provide a wet surface for particulate impingement. Particles impact the wetted packing and are subsequently flushed to the bottom of the scrubber. Gas flow may be concurrent, countercurrent, or crossflow to the liquid stream.

The performance of a packed tower is directly influenced by the size, shape and type of packing material. Small packing material with high ratios of surface area to volume are usually desirable, although clogging may be a problem with small, intricate packings. The depth of packing does not have a great effect on particulate removal once a minimum depth is provided. This minimum depth has been reported to be 10 - 12 times the major dimension of the packing pieces.[16]

Velocity through the tower also affects performance. Higher velocities increase impingement of medium and large particles.[17] For very small particles (less than .3 microns) a low velocity may be desirable to assist removal via diffusion.[18]

Pressure drops depend on packing type and depth. Approximately .123 kPa (.5 in. W.G.) per foot of bed is typical for most packings. Total pressure drop through the scrubber is typically between .5 kPa (2 in. W.G.) and 2.5 kPa (10 in. W.G.).[19] Liquid use is normally .267 - .669 liters/m^3 of gas (2 - 5 gal/1000 ft^3).[20]

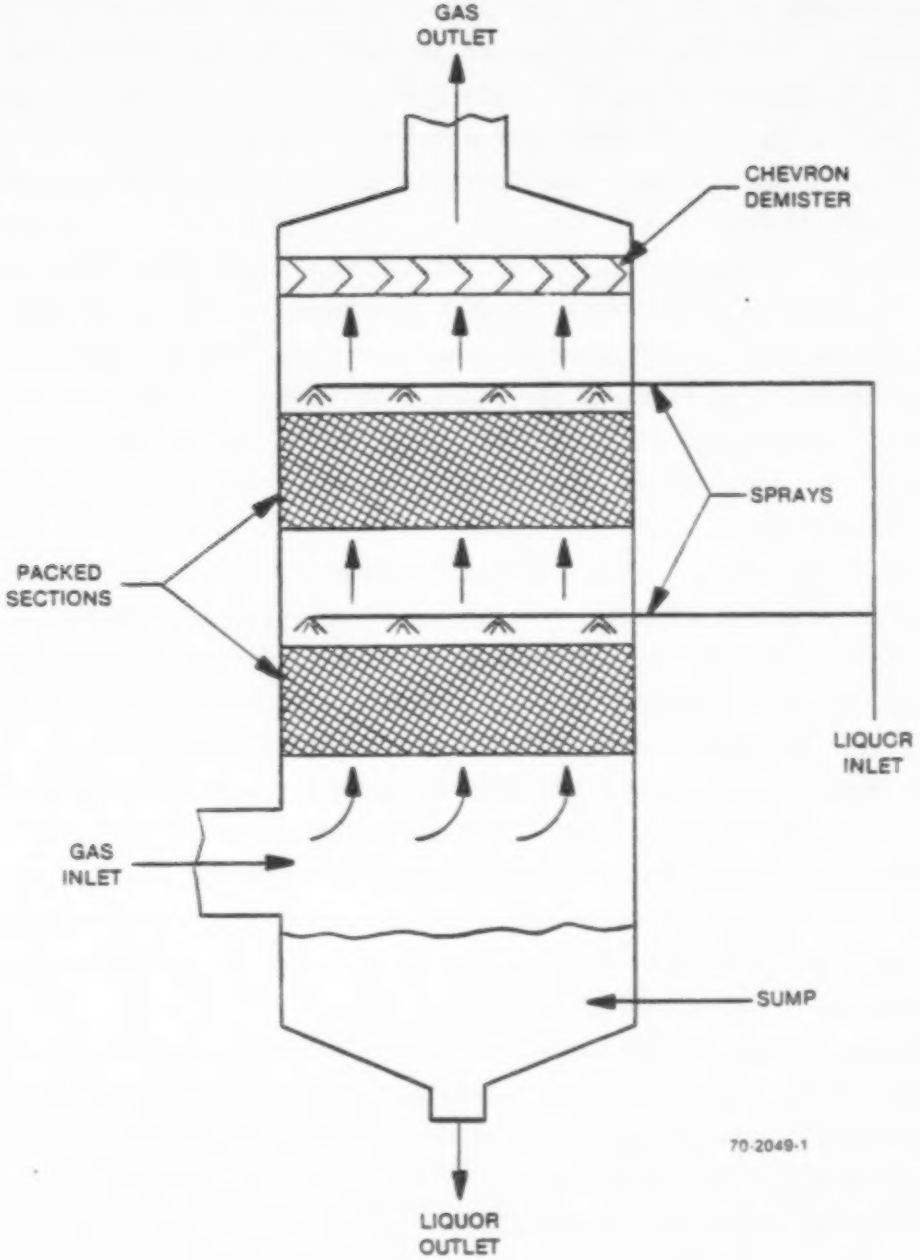

Figure 4-2. Typical packed tower scrubber.

The major disadvantage of packed beds is their susceptibility to clogging under high particulate loadings. A moving bed alleviates this problem to some extent by providing a semi-fluidized packing, usually of plastic spheres. The spheres rotate and jiggle slightly, constantly exposing clean areas which collect particles. Higher gas velocities, a result of fluidizing the packing material, increase turbulence and gas-liquid contact. Pressure drops for these scrubbers are about double a conventional packed bed.[21]

4.2.1.3 Mechanically Aided Scrubbers. Mechanically aided scrubbers rely on a motor driven device between the inlet and outlet of the scrubber body to effect particle removal. This device also serves as the fan which draws air through the scrubber. Particles are collected by impaction upon the fan blades as the gas flows through the scrubber. Liquid is typically introduced at the hub of the rotating fan blades. Some liquid atomizes upon fan impact, while some runs over the blades, washing them of collected particulate. This latter portion atomizes as it leaves the fan wheel. The liquid is recaptured by the fan housing, which drains into a sump. Figure 4-3 shows an example of a mechanical centrifugal scrubber.

The performance of this scrubber is influenced by the total energy input to the fan and the liquid flow rate provided. Higher fan velocities generally cause greater impingement of particles on the fan blades. Likewise, increased liquid flow rates increase particle removal.[22]

4.2.1.4 Tray Type Scrubbers. A tray type scrubber is shown in Figure 4-4. It consists of a vertical tower containing one or more transversely mounted trays. Particulate laden gas enters the tower bottom and bubbles through valves, perforations, or other types of openings in each tray before exiting through the top of the tower. Scrubbing liquid is usually introduced at the top tray, and flows across each tray, over a restraining dam, and through a downcomer to reach the tray below. The particulate laden liquid exits the bottom of the tower. Gas passes through the openings in each tray and bubbles through the liquid flowing over the tray. Liquid-gas contacting causes the mass transfer and particle removal.

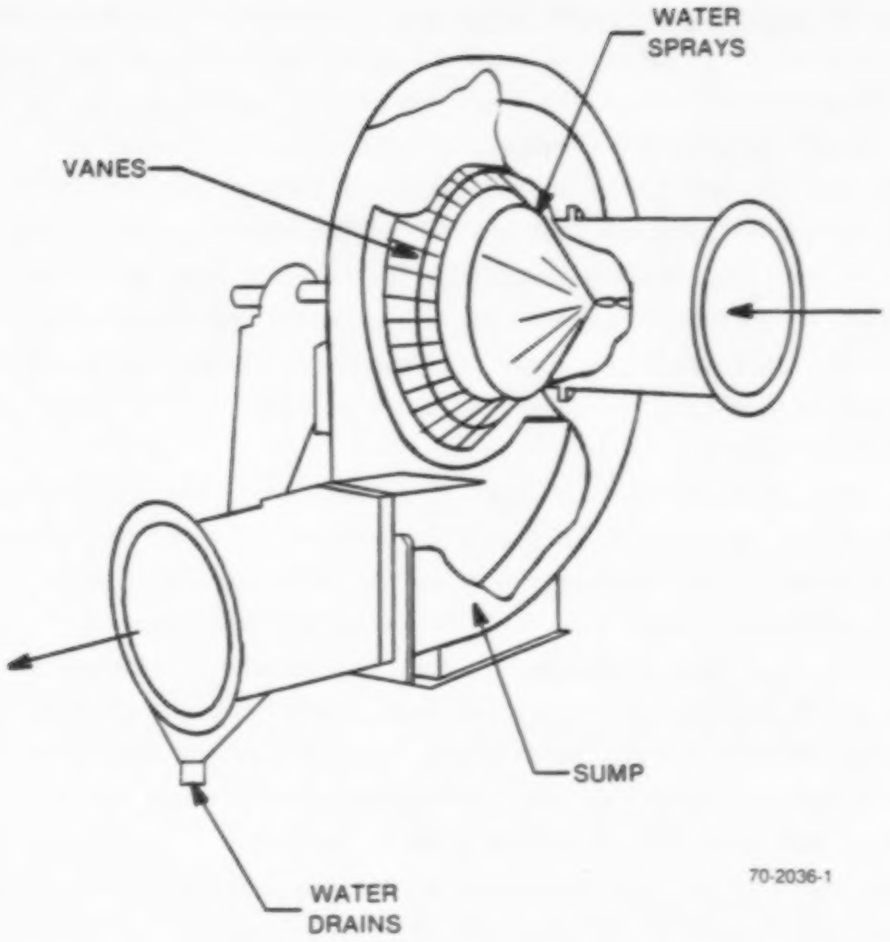

Figure 4-3. Typical mechanically aided scrubber.[50]

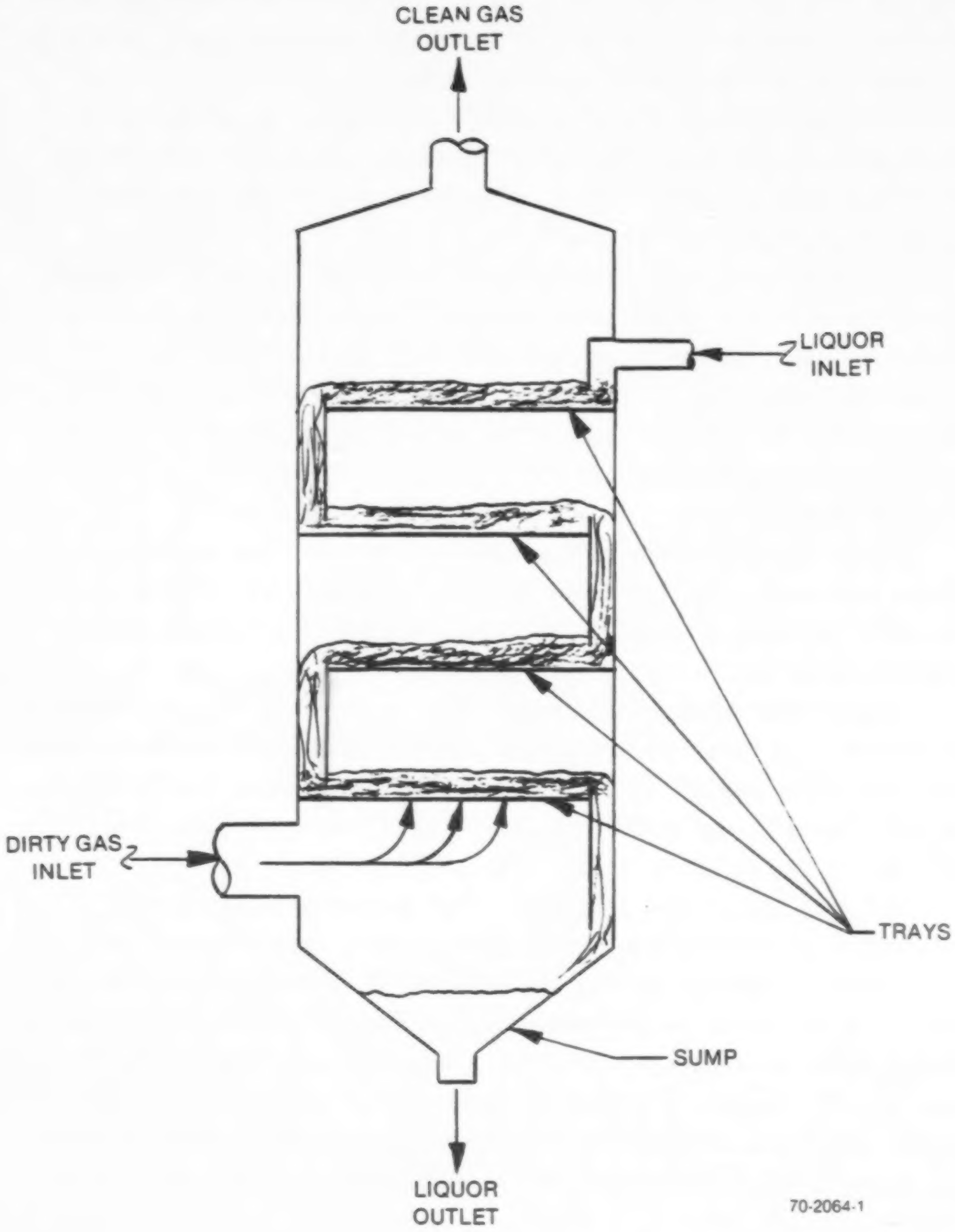

Figure 4-4. Typical tray-type scrubber.

As the diameter of the tray perforations decreases, the collection efficiency for smaller particles usually improves. A tray type scrubber does not have the same efficiency for all particle sizes, but instead exhibits a sharp efficiency drop at a specific particle size. This size is determined by the size of the tray perforations.[23]

The pressure drop through a plate type scrubber is determined by the size of the orifices, the number of trays, and the velocity of the gas stream through the scrubber. In general, higher pressure drops result in greater efficiencies.[24]

Although, some texts indicate that increasing the number of trays has little effect on particulate removal,[25]manufacturer's performance curves show an increase in removal with more trays. Figure 4-5 illustrates this effect for a tray type scrubber used in the urea industry for a variety of particle sizes. The efficiency on the vertical axis, termed standard efficiency, is for a standard .375 kPa (1.5 in. W.G.) pressure drop per tray.

Figure 4-6 illustrates the effect of increasing the pressure drop across each tray. For any given standard efficiency at .375 kPa (1.5 in. W.G.) per tray obtained from Figure 4-5, the efficiency at higher pressure drops may be read from Figure 4-6.

Liquid flow rate can have some effect on particle removal, however, an optimum flow rate is usually maintained which insures adequate liquid for particulate removal without blocking airflow through tray orifices. Typical liquid to gas ratios are .0669 - .401 liters/m^3 (.5 - 3 gal/1000 ft^3) at 172 kPa (25 psig) liquor pressure.[26]

4.2.1.5 Entrainment Scrubbers. Entrainment scrubbers (also referred to as orifice type, self-induced spray, or impingement and entrainment scrubbers) utilize the velocity of the gas stream over the surface of a liquid, in combination with a sudden change in direction of the gas flow, to remove particulates. A common entrainment scrubber used in urea industry applications is shown in Figure 4-7. The gas stream enters the circular housing, where it is forced through a narrow gap formed between the surface of the sump liquor and an inner housing.

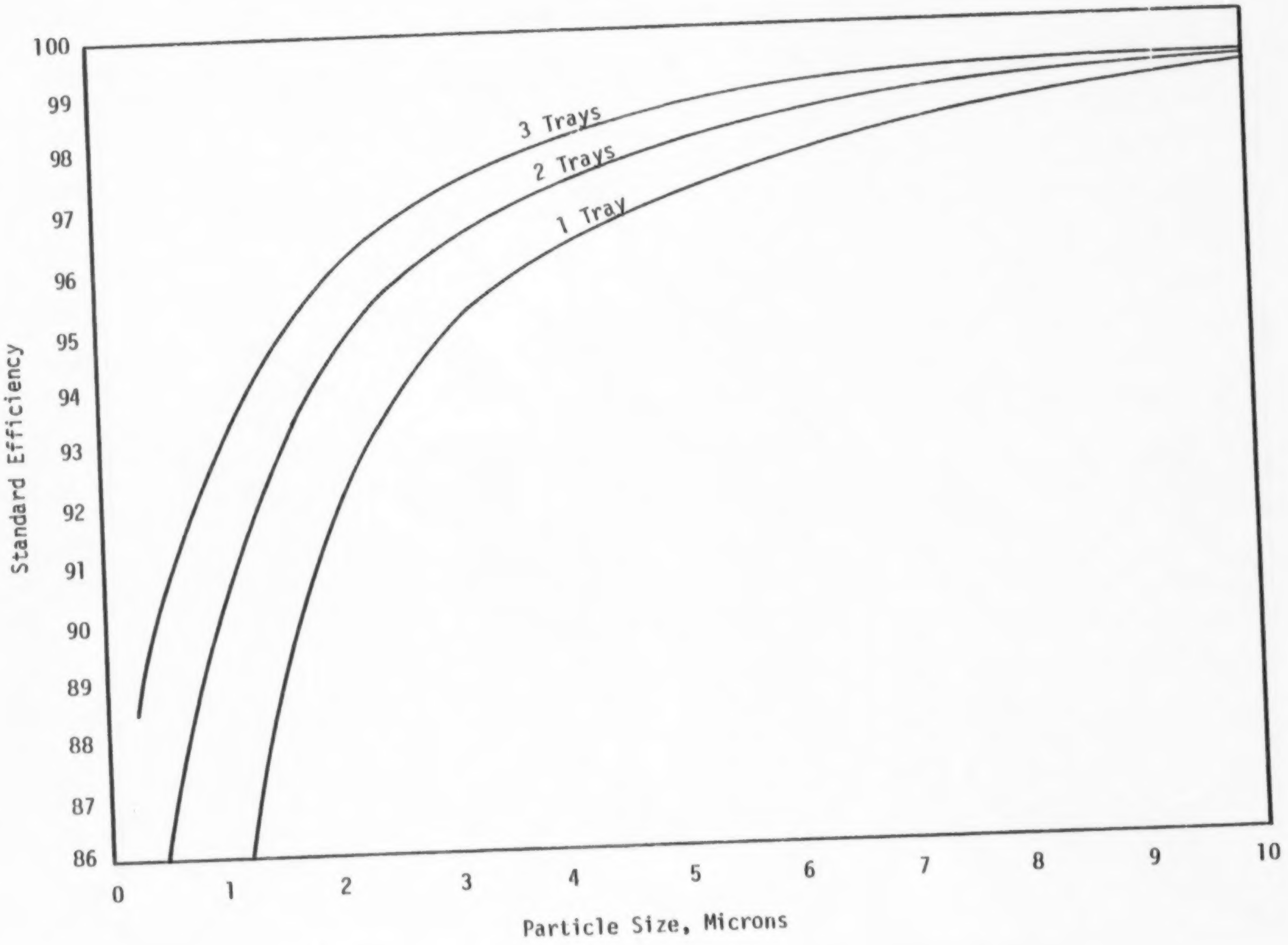

Figure 4-5. Standard fractional efficiency for tray type scrubber.

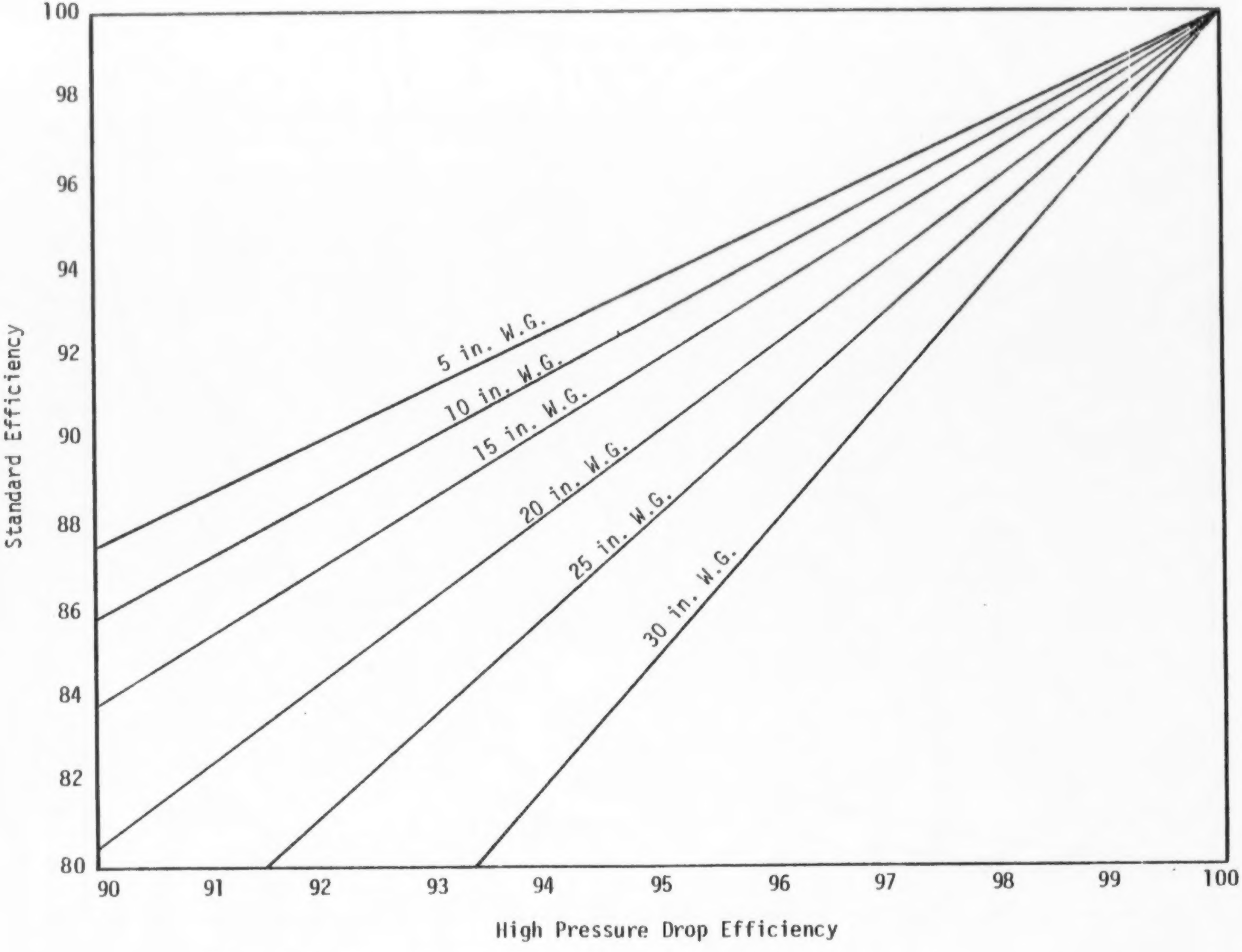

Figure 4-6. Effect of pressure drop on tray type scrubber efficiency.

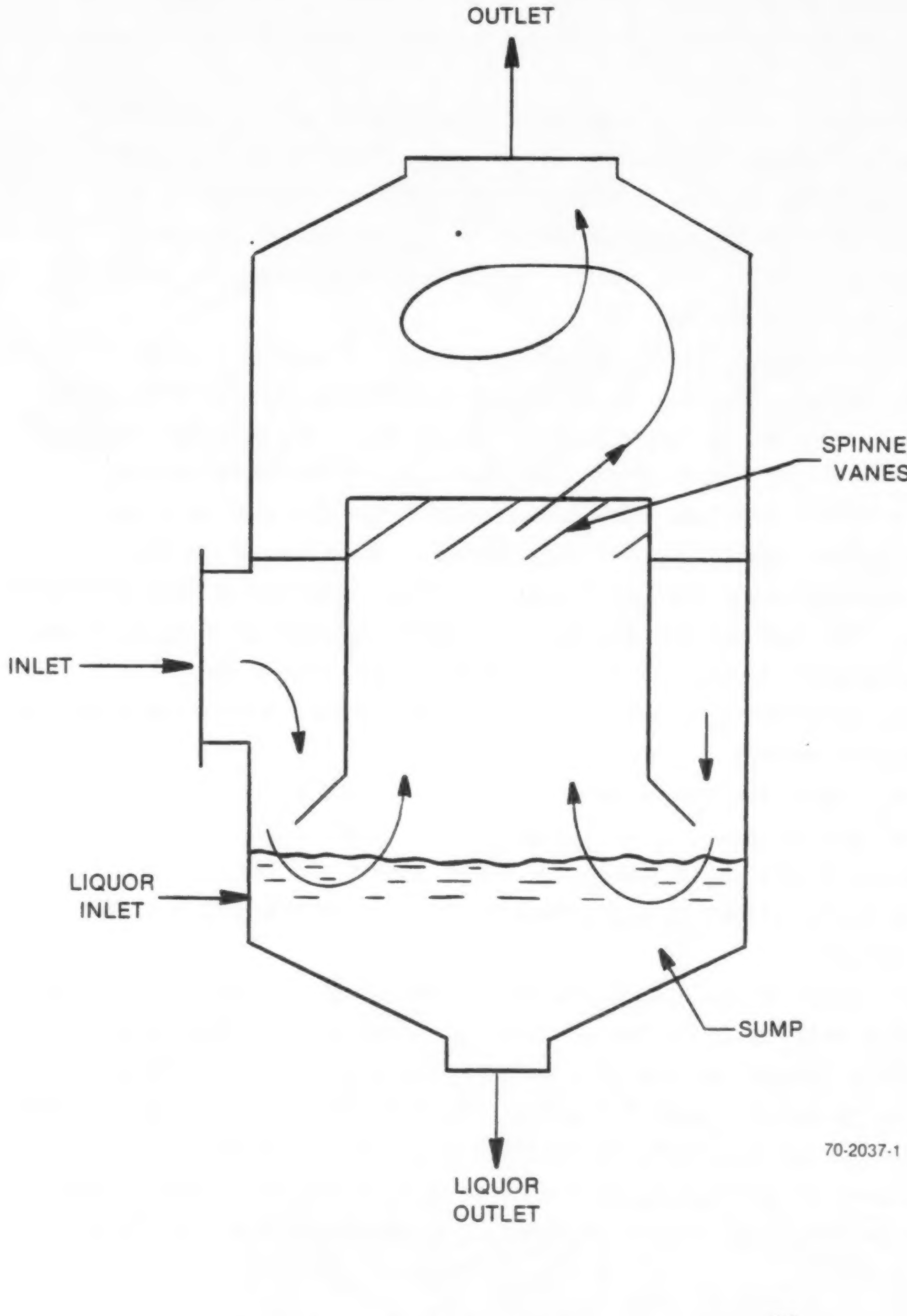

Figure 4-7. Typical entrainment scrubber.[53]

A turbulent zone is established at this gap promoting spray droplet formation and dispersion as the gas abruptly changes directions. The moisture laden stream is then demisted by swirl vanes before exiting the scrubber.

The primary factor influencing the performance of the entrainment scrubber is pressure drop across the device. The effect of pressure drop and particle size on scrubber efficiency is illustrated in the fractional efficiency curves presented in Figure 4-8. Entrainment scrubbers used in the urea industry operate at widely varying pressure drops depending on the application.

4.2.1.6 Fibrous Filter Scrubbers. A type of wetted fibrous filter scrubber has recently been installed and operated to control prill tower emissions. The device is depicted in Figure 4-9. The scrubber utilizes a filter installed over a perforated drum. The filter drum rotates slowly through a shallow liquor bath and is also irrigated by spray nozzles located throughout the drum chamber. Gases pass from the exterior of the drum, through the wetted filter, and into a mist eliminator section. The demister housing is a horizontal cylinder with an inclined demister element located near the scrubber exit. Flow through the prill tower and scrubber is induced by an axial fan mounted downstream from the demister section.

The filter itself is a dense fibrous mat. For prill tower control, a Teflon^R mat is used.[27] As the particles travel at high velocity through the filter, they impact the wetted fibers and are held until they are washed either by the sprays or the bath at the bottom of the filter housing.

The design of the wetted fibrous filter allows the pressure drop to be readily adjusted while the scrubber is in operation. This adjustment is possible through the use of a moving, semi-cylindrical baffle plate which may be used to cover a fraction of the filtration drum. By covering a portion of the drum face, the airflow is forced to travel through a smaller area on the drum which increases face velocities. These higher velocities result in greater impingement of particulate on the filter

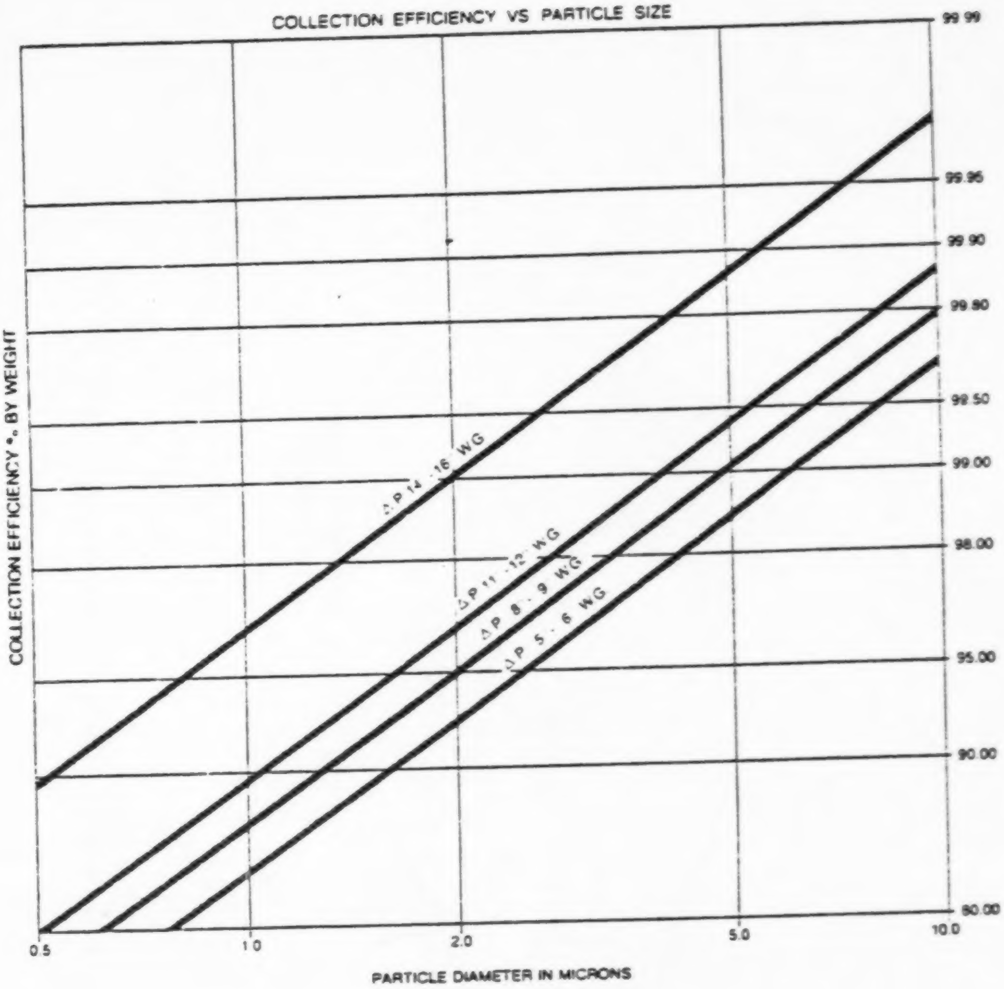

Figure 4-8. Fractional efficiency of entrainment scrubber used in the urea industry as a function of particle size and pressure drop (courtesy of the Western Precipitation Division of Joy Manufacturing Company).[54]

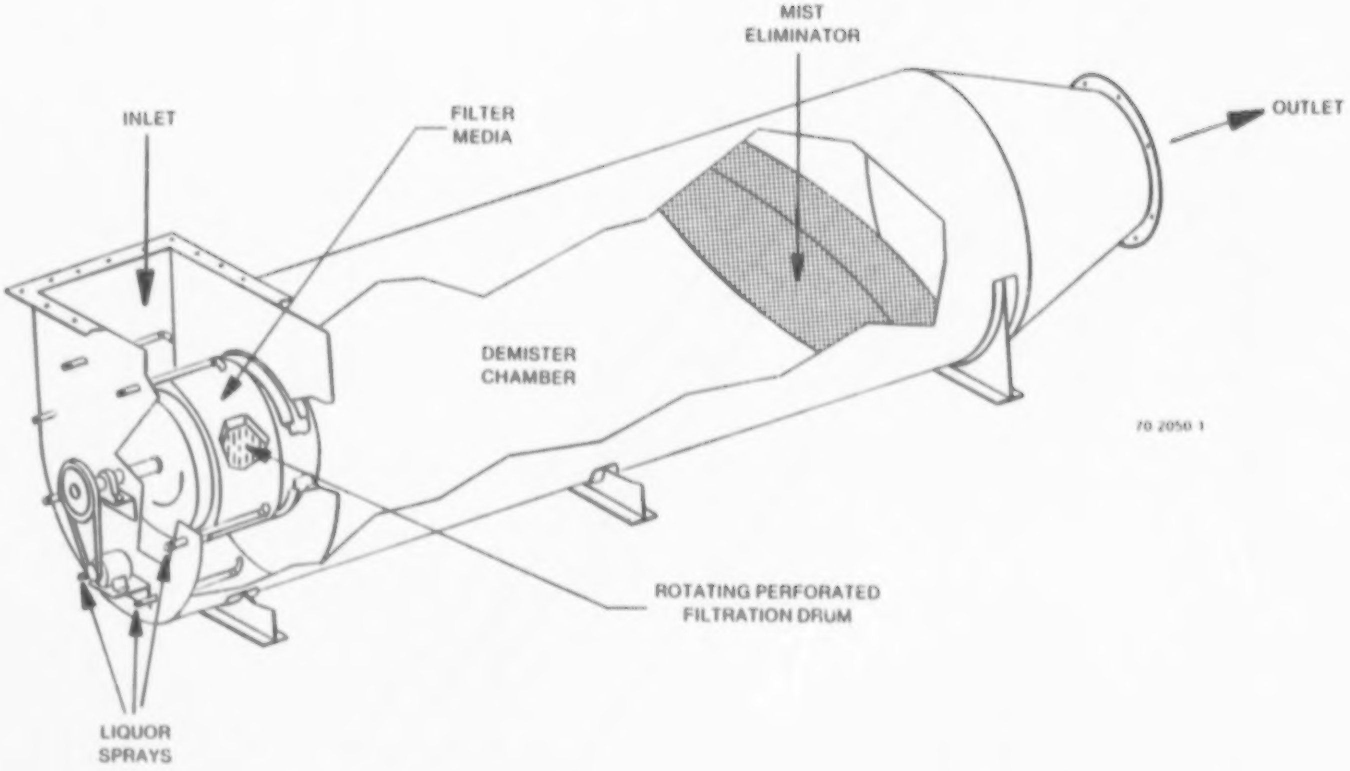

Figure 4-9. Typical fibrous filter scrubber.[55]

mat and increase removal efficiency at the expense of higher pressure drop.

The baffle may also be used to hold the pressure drop constant at various airflows through the scrubber. This feature allows collection efficiencies to be maintained while producing different grades of product which require different airflows.

Figure 4-10 presents the efficiency of the wetted fibrous filter as a function of particle size. This curve was obtained during prill tower testing of a Teflon^R filter scrubber operating at 4.75 kPa (19 in. W.G.). According to the vendor, improvements have been made to the scrubber since this test, which allow this performance curve to be met with pressure drops in the range of 3.0 - 3.75 kPa (12 - 15 in. W.G.).[28] The effect of pressure drop on particulate removal efficiency is illustrated in Figure 4-11.

The plant where the wetted fibrous filter is used to control prill tower emissions uses a preconditioning system involving liquor injections in the ductwork prior to the scrubber. This preconditioning system is reported to cause particle agglomeration prior to the scrubber and thus increase the scrubber's effectiveness. Details of the preconditioning system are considered proprietary by company personnel.

The wetted fibrous filter may be operated at from 2.5 - 7.5 kPa (10 - 30 in. W.G.) differential pressure drop across the device. Typical liquid recirculation requirements (scrubber only) are .134 - .267 liters/m^3 of gas (1 - 2 gal/1000 ft^3). Spray nozzle pressure is approximately 138 kPa (20 psig).[29]

4.2.2 Fabric Filters

Fabric filters (baghouses) are high efficiency collection devices used quite extensively throughout the chemical processing industry. Design variables for baghouses include method of cleaning, choice of fabric, size of the unit, air-to-cloth ratio, and whether the baghouse is a pressure or suction unit.

Figure 4-12 depicts a typical fabric filter system. In the type of design shown, the airstream enters the baghouse and is pulled up into

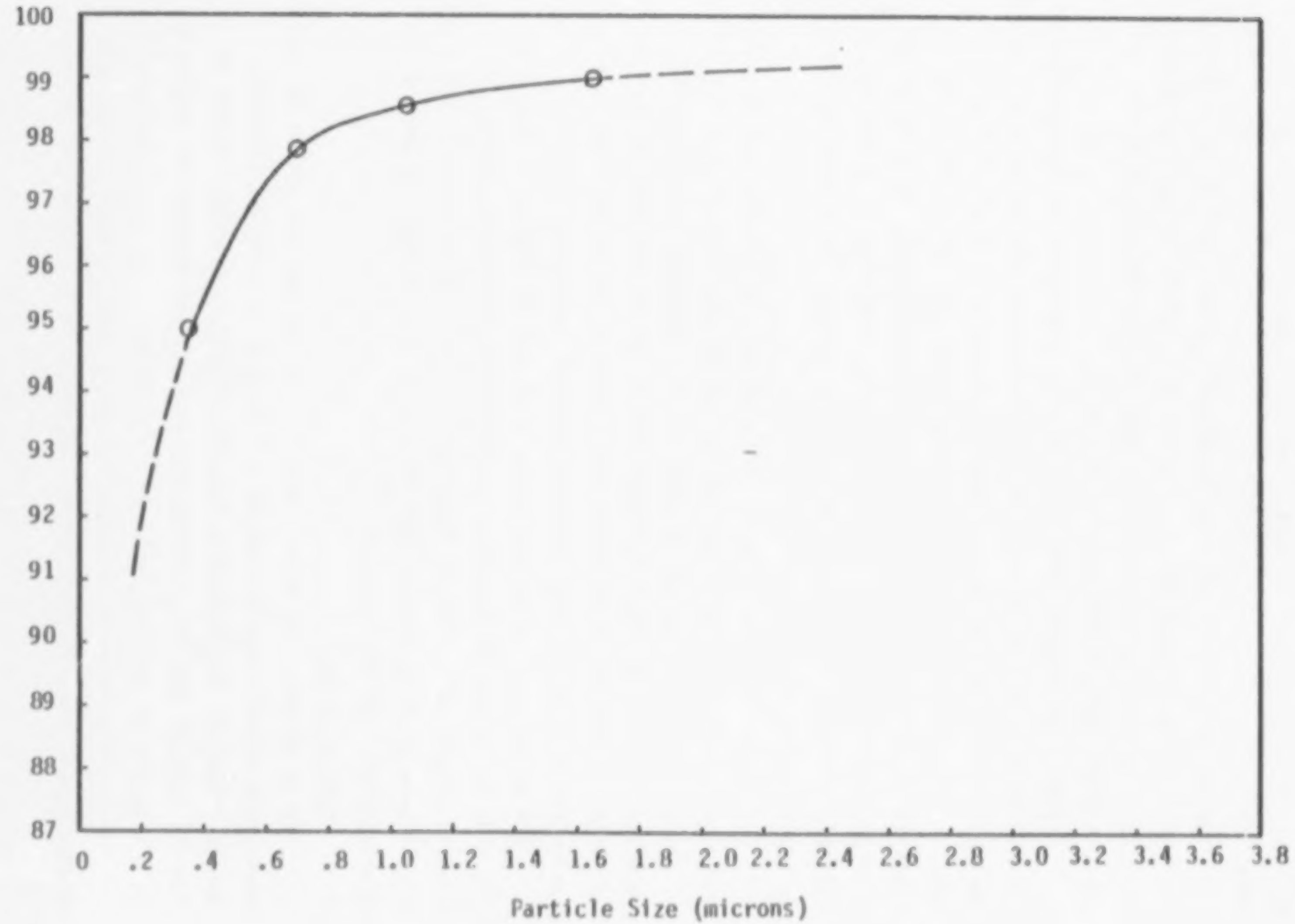

Figure 4-10. Fractional Efficiency of Wetted Fibrous Filter Scrubber[56]

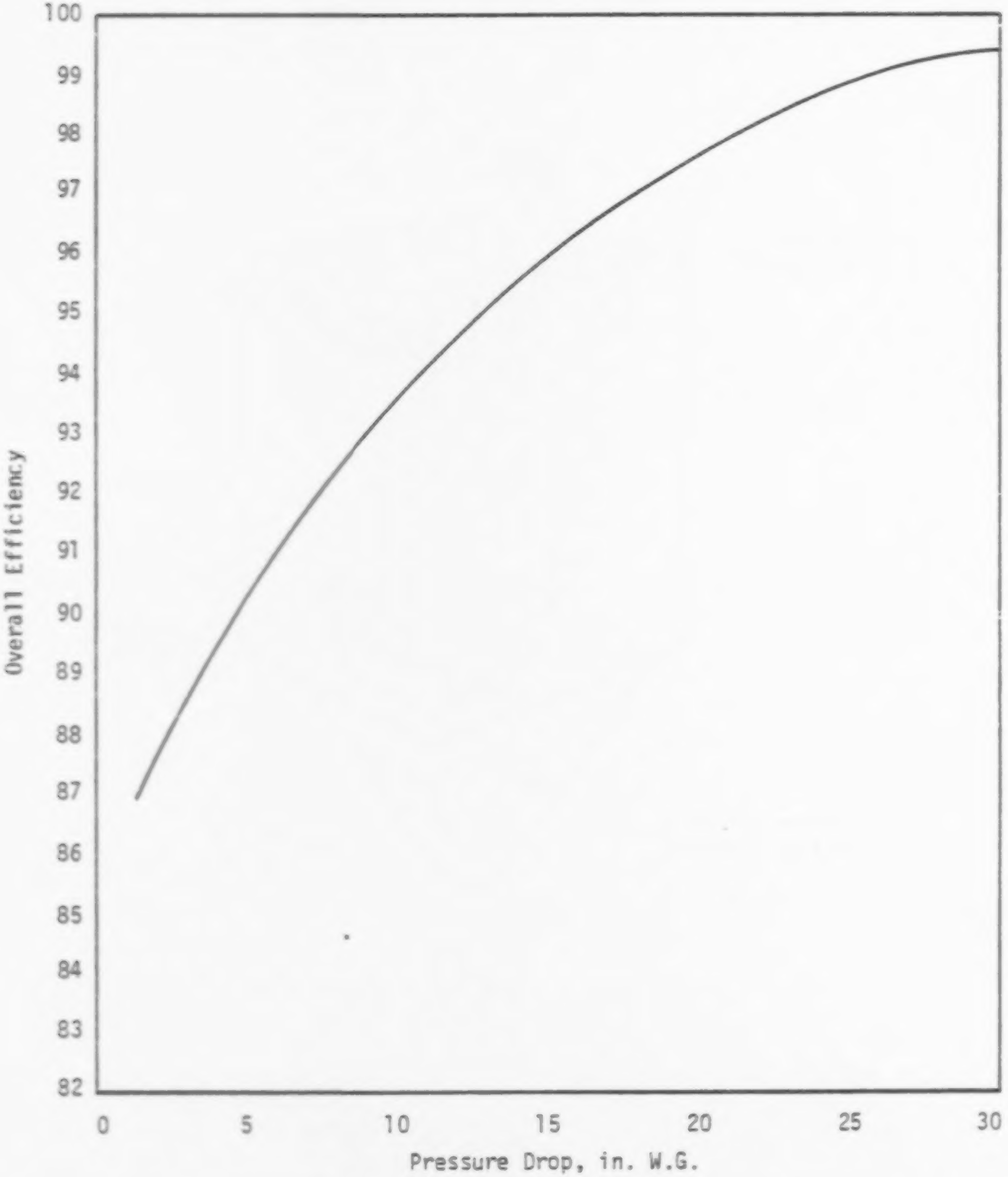

Figure 4-11. Effect of pressure drop on efficiency of wetted fibrous filter scrubber.[57]

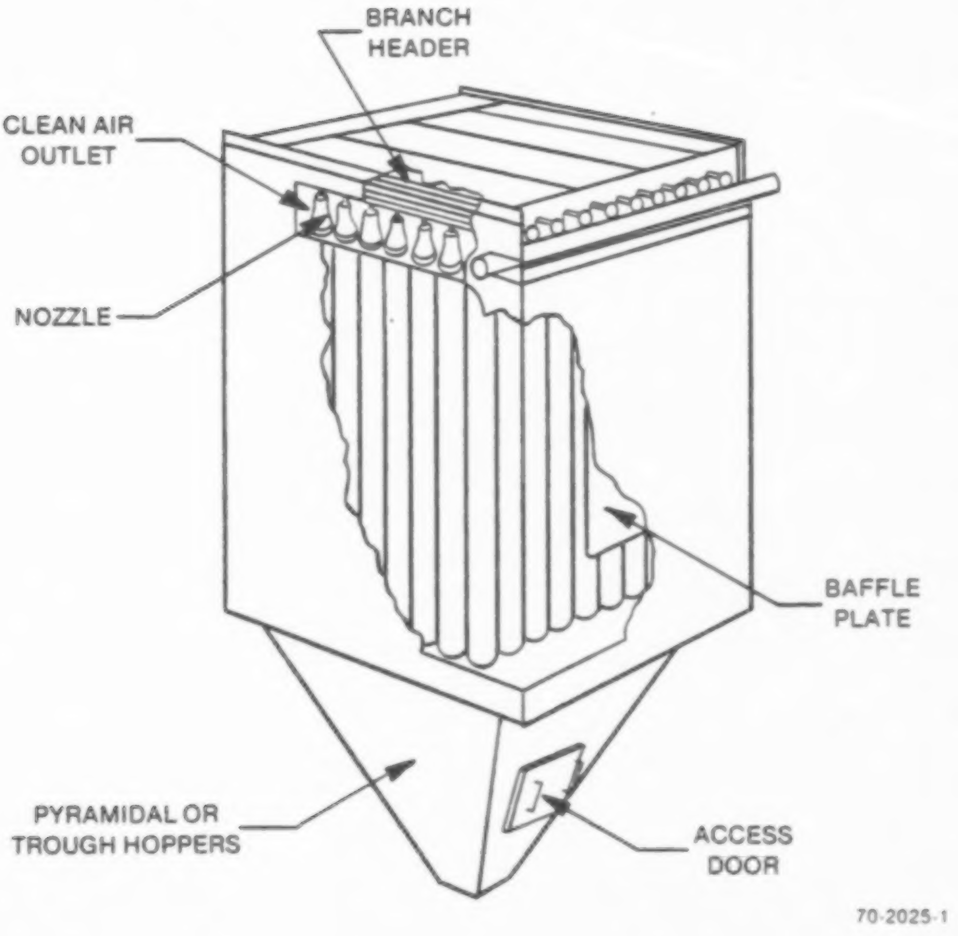

Figure 4-12. Diagram of a Fabric Filter.[58]

fabric sleeves located throughout the baghouse. Air is pulled through these fabric sleeves and exhausted to the atmosphere while dust remains trapped in the weave of the fabric, forming a layer of dust on the bag. The pressure drop through the bag increases as this dust layer builds up. The dust is periodically removed from the bag by one of several bag cleaning methods.

Two methods of cleaning are shaking (rapping) and reversing the airflow through the bag by air jets or pulses. Shaking consists of manually or automatically shaking the bag hangers or rapping the side of the baghouse to shake the dust free from the bags and into a receiving hopper below. In the jet pulse method, compressed air is released at regular intervals in to a group of bags, causing the bags to pulse and the dust to be released.

Cleaning can be either continuous or intermittent. Intermittent cleaning consists of shutting down the baghouse or a section of the baghouse when it reaches its highest design pressure drop. For continuous cleaning, individual bags are cleaned at regular, timed intervals.

An important operating principle for fabric filters is that effective filtering of the dusty airstream is accomplished not only by the fabric, but also by the dust layer which forms on the fabric. This dust layer bridges the gaps between adjacent fibers and increases the chances of impaction and interception of small particles. For this reason, too frequent cleaning can actually decrease efficiency by not allowing a dust layer to accumulate between cleaning cycles.

The urea dust layer can cause problems in urea industry applications due to the hygroscopic nature of urea particulate. The dust layer can absorb moisture in the air and cause the formation of a sticky cake. This cake increases the pressure drop and can cause difficulties in cleaning. For this reason, use of baghouses in the urea industry is currently limited to process airstreams with low moisture contents, such as bagging operations.

Materials available for bag construction are numerous. They include cotton, Teflon^R, coated glass, orlon, nylon, dacron and wool. Temperatures, frequency of cleaning, ease of removing particles, resistance to chemical attack, and abrasion characteristics of the collected particles determines the type of bag fabric material.

Factors affecting baghouse performance include air to cloth ratio, type of fabric used, method and interval of cleaning, pressure drop, and the properties of the dusty exhaust being cleaned. Air to cloth ratio is dimensionally equivalent to a velocity, and thus indicates the average face velocity of the gas stream through the effective area of the fabric. An excessive filter ratio results in excessive pressure loss, reduced collection efficiency, rapid bag blinding, and increased wear on the fabric. Too low an air to cloth ratio results in an oversize unit and can also reduce collection efficiency since an adequate filtering dust dayer may not be allowed to accumulate between cleaning cycles.

Pressure drops in baghouses depend on a variety of factors including the air to cloth ratio, fabric type, and cleaning cycle. Pressure drops typically increase between cleaning cycles as the dust layer builds. Pressure drops of from .5 - 2 kPa (2 - 8 in. W.G.) are common for many applications.[30] Air to cloth ratios range from 2 to 10 with 3 being the typical ratio reported in the urea industry. Methods used in the industry for cleaning baghouses include mechanical shaking, reverse pulse airflow, and vibration. Types of cloth material commonly used in the industry include cotton, dacron and polyester.[4,5,6]

4.3 EMISSION TEST DATA

Available data concerning control device performance is broken down into two basi types: data supplied by industry and state air pollution agencies (hereafter referred to as industry data), and data collected by EPA during source testing conducted for this study (hereafter referred to as EPA data). In general, the available industry data is very limited. Industry data presented in this section is confined to mass emission measurements of prill towers and coolers. It should be noted that the industry data vary widely in test procedures and sampling techniques. In particular, significant difficulties exist in sampling emissions from prill towers due to their design. Comparisons between the two types of data are not intended to imply that the sampling and test procedures are similar.

Tables 4-2 and 4-3 present an overall summary of EPA mass emission test results and visible emission test results, respectively. Appendix A presents details of the test data and testing program.

As can be noted in Table 4-2, control of ammonia emissions to a significant degree is not currently demonstrated in the urea industry. In fact, most test data indicates an increase in ammonia emissions across the control device. Control of formaldehyde emissions is quite variable, however, the level of formaldehyde in the control device inlet is usually quite low to begin with. Because ammonia control is not currently demonstrated in the industry and formaldehyde emissions are small, the following subsections will address control device performance in terms of particulate removal only.

4.3.1 Emission Data for Nonfluidized Bed Prill Towers

Table 4-4 presents the available industry data for controlled nonfluidized bed prill towers consisting of four tests conducted at three plant sites. Two of these three plants were also tested by EPA. (Plant E and Plant C.) Test results for Plant E are presented in Appendix A, Tables A-63 through A-65. Tests at Plant E represent measurements of a nonfluidized bed prill tower producing agricultural grade product. This plant uses a wetted fibrous filter. The tests (Appendix A, Tables A-63, and 64 versus Tables A-65 and 66) differ in the type of preconditioning sprays used in the ductwork prior to the scrubber. Tables A-65 and 66 represent full preconditioning as the plant normally operates and Tables A-63 and 64 represent testing with partial preconditioning. Preconditioning is used to encourage particle agglomeration prior to the scrubber. According to these tests, full preconditioning shows improvement in outlet mass emissions (0.22 g/kg and .044 lb/ton) compared to the partial preconditioning (.320 g/kg and .640 lb/ton).

TABLE 4-2. SUMMARY OF EPA MASS EMISSION TEST RESULTS

				Particulate Emissions			Ammonia Emissions			Formaldehyde Emissions		
Process	Control Device	Plant	Production Rate Mg/day (ton/day)	Control Device Inlet kg/Mg (lb/ton)	Control Device Outlet kg/Mg (lb/ton)	Collection Efficiency %	Control Device Inlet kg/Mg (lb/ton)	Control Device Outlet kg/Mg (lb/ton)	Collection Efficiency %	Control Device Inlet kg/Mg (lb/ton)	Control Device Outlet kg/Mg (lb/ton)	Collection Efficiency %
NFB Prill Tower - AG Product	Packed Tower Scrubbers	C	268 (295)	NA[a]	.188 (.375)	NA	NA[a]	0.640 (1.28)	NA	NA[b]	NA	NA
NFB Prill Tower - AG Product	Wetted Fibrous Filter	E	266 (293)	1.88 (3.76)	.0271 (.0541)	98.3	0.326 (.653)	2.18 (4.36)	< 0	NA[b]	NA	NA
FB Prill Tower - AG Product	Entrainment Scrubber	D	979 (1078)	3.12 (6.24)	.392 (.785)	87.6	1.39 (2.78)	3.25 (6.50)	< 0	.00910 (.0182)	.000420 (.000839)	95.4
FB Prill Tower - FG Product	Entrainment Scrubber	D	1020 (1123)	1.80 (3.59)	.240 (.479)	86.7	1.99 (3.98)	1.04 (2.08)	49.7	.00190 (.00380)	.000500 (.000999)	74.8
Drum Granulator	Entrainment Scrubber	A	356 (392)	149 (298)	.115 (.230)	99.9	1.08 (2.16)	3.07 (6.14)	< 0	.00359 (.00717)	.00136 (.00271)	62.2
Drum Granulator	Entrainment Scrubber	B	NA[c]	63.6 (127.2)	.122 (.244)	99.8	1.07 (2.13)	.845 (1.69)	20.5	.000380 (.000560)	.000125 (.000250)	50.2

[a] Inlet tests not conducted during outlet tests. Earlier inlet tests considered nonrepresentative (see Appendix A).

[b] Formaldehyde tests not conducted.

[c] Production rate considered confidential by company.

Data is averaged for tests A-1 and A-2

Legend:	
AG - Agricultural Grade	FB - Fluidized bed
FG - Feed Grade	NA - Not available
NFB - Nonfluidized bed	

TABLE 4-3. SUMMARY OF EPA VISIBLE EMISSION TEST RESULTS

Process	Control Device	Plant	Opacity Measurements (%)			
			Observations[a]	Min.	Max.	Average
NFB Prill Tower - AG Product	Packed Tower	C	158	.2	37.0	9.68
NFB Prill Tower - FG Product	Packed Tower	C	42	5.0	54.4	16.8
NFB Prill Tower - AG Product	Fibrous Filter	E	179[c]	0	27.1	9.33
FB Prill Tower - AG Product	Entrainment Scrubber	D	117[b]	10.0	41.2	25.3
FB Prill Tower FG Product	Entrainment Scrubber	D	106[b]	3.3	33.3	20.8
Drum Granulator	Entrainment Scrubber	A	79	0.0	5.0	2.92
Drum Granulator	Entrainment Scrubber	B	62	5.0	9.7	7.62
Bagging Operations	Fabric Filter	D	35	0.0	1.0	.05
Rotary Drum Cooler	Packed Tower	E	10	1.0	4.4	3.0
Rotary Drum Cooler	Entrainment Scrubber	C	11	15.0	27.0	22.0

[a] Six minute average

[b] Includes measurements both on individual scrubbers and on prill tower as a whole.

[c] Data is for both tests conducted at Plant E.

Legend: NFB - Nonfluidized bed
FB - Fluidized bed
AG - Agricultural Grade
FG - Feed Grade

TABLE 4-4. SUMMARY OF INDUSTRY MASS EMISSION TEST RESULTS FOR CONTROLLED PRILL TOWERS[29,48]

Plant	Tower Type	Product	Production Mg/day (tons/day)	Control Device	Pressure Drop kPa (in. W.G.)	Airflow dsm^3/min (dscfm)	Particle Concentration g/dsm^3 (gr/dscf)	Emission Rate g/min (lb/hr)	Emission Factor kg/Mg (lb/ton)	Device Efficiency %
E	NFB	AG	272 (300)	Wetted Fibrous Filter	2.5-4.75 (10-19)	2,410 (85,000)	.00183 (.0008)	4.41 (.583)	.0271 (.0541)	98.8
H[a] (two towers)	NFB	-	218 (240)	-	-	3,750 (132,400)	.00586 (.00256)	22.0 (2.91)	.146 (.291)	-
	NFB	-	999 (1100)	-	-	10,200 (359,000)	.00701 (.00306)	71.2 (9.41)	.103 (.205)	-
C[b]	NFB	AG	272 (300)	Packed Tower	.5 (2)	1,530 (53,900)	.00701 (.00310)	11.0 (1.45)	.0580 (.116)	91.6
D[c] (two products)	FB	FG	923 (1017)	Entrainment Scrubber	1.25 (5)	8,520 (301,000)	.0321 (.0140)	273 (36.1)	.426 (.852)	86.3
	FB	AG	946 (1042)	Entrainment Scrubber	1.25 (5)	12,470 (440,200)	.0198 (.00867)	247. (32.7)	.377 (.753)	79.0
N[b]	FB	-	629 (693)	Spray Tower	-	3,790 (133,800)	.0490 (.0214)	185. (24.5)	.425 (.849)	-

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[a] Testing method usedwas standard EPA Method 5. Type of product, type of control device, pressure drop, and uncontrolled emission rates are not available.

[b] Testing done using wet impinger train. Pressure drop during test not available. Pressure drop given measured during EPA test. Device efficiency based on uncontrolled emissions as given in Chapter 3.

[c] Isokinetic sampling used, however, analysis method is unknown. Pressure drop not recorded during test. Pressure drop given measured during EPA test.

[d] Tracer gas used to determine flow rates and maintain isokinetic sampling. Wet impinger train used. Type of product and pressure drop unavailable.

Legend:	
NFB - Nonfluidized bed	AG - Agricultural Grade
FB - Fluidized bed	FG - Feed Grade

The EPA test results for Plant C are presented in Appendix A, Tables A-26 and A-27. These results represent measurements of a nonfluidized bed prill tower producing agricultural grade product. The emission control system at this plant consists of four packed bed scrubbers operated in parallel. One scrubber was tested and the total emissions were determined by factoring the single emission measurement by four. This assumes that the tested scrubber is representative of the remaining three. Velocity traverses and visible emission observations of the untested scrubbers show this assumption to be reasonable (see Appendix A).

Particle size tests were conducted at Plants C and E on prill tower exhausts entering the scrubbers. At Plant C, tests were run during production of both agricultural and feed grade production. This data, presented in Figure 4-13, shows a shift toward larger particles during feed grade production as evidenced by a shift to the left of the cumulative distribution plot. At Plant E, the particle size distribution during agricultural grade production (Plant E does not produce feed grade urea) was measured. This data is presented in Figure 4-14.

One industry particle size test for a nonfluidized bed prill tower is available and is presented in Figure 4-15. This data also shows a shift toward larger particles during feed grade production.

Visible emission data were gathered by EPA during the tests at Plant C and E. Figure 4-16 presents histograms of the visible emission data collected at Plant C during both agricultural grade and feed grade tests. Opacity during feed grade production averaged somewhat higher. During feed grade production at Plant C, prill tower fans are shut off and the tower airflow is induced by natural draft only. This results in lower air velocities and pressure drops in the scrubbers, which may contribute to higher opacity readings during feed grade production. Figure 4-17 presents histograms of the visible emission data collected at Plant E. These tests both involved agricultural grade production and differ only in the preconditioning system used. Opacity readings were generally higher with full preconditioning.

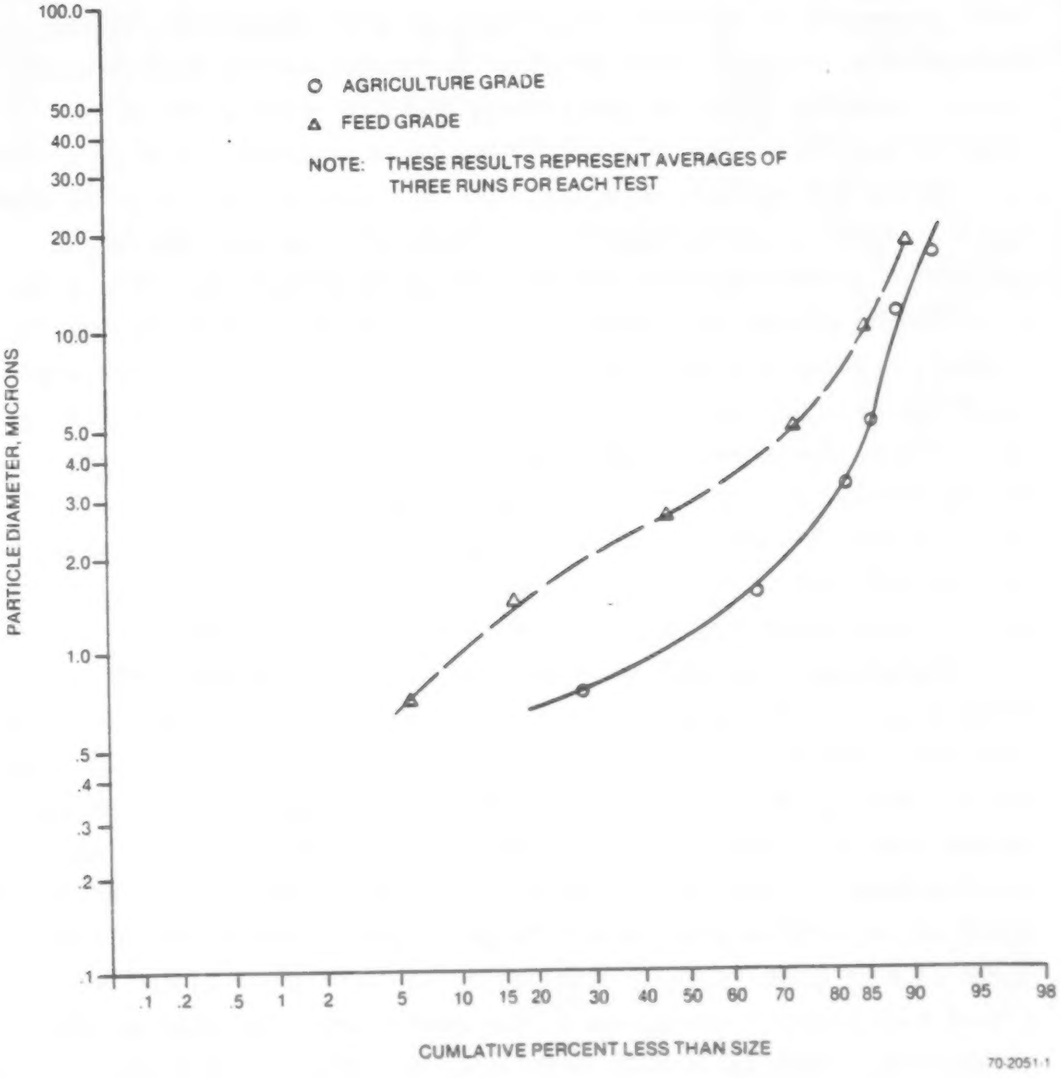


Figure 4-13. Particle size distribution of uncontrolled NFB prill tower exhaust (Plant C).

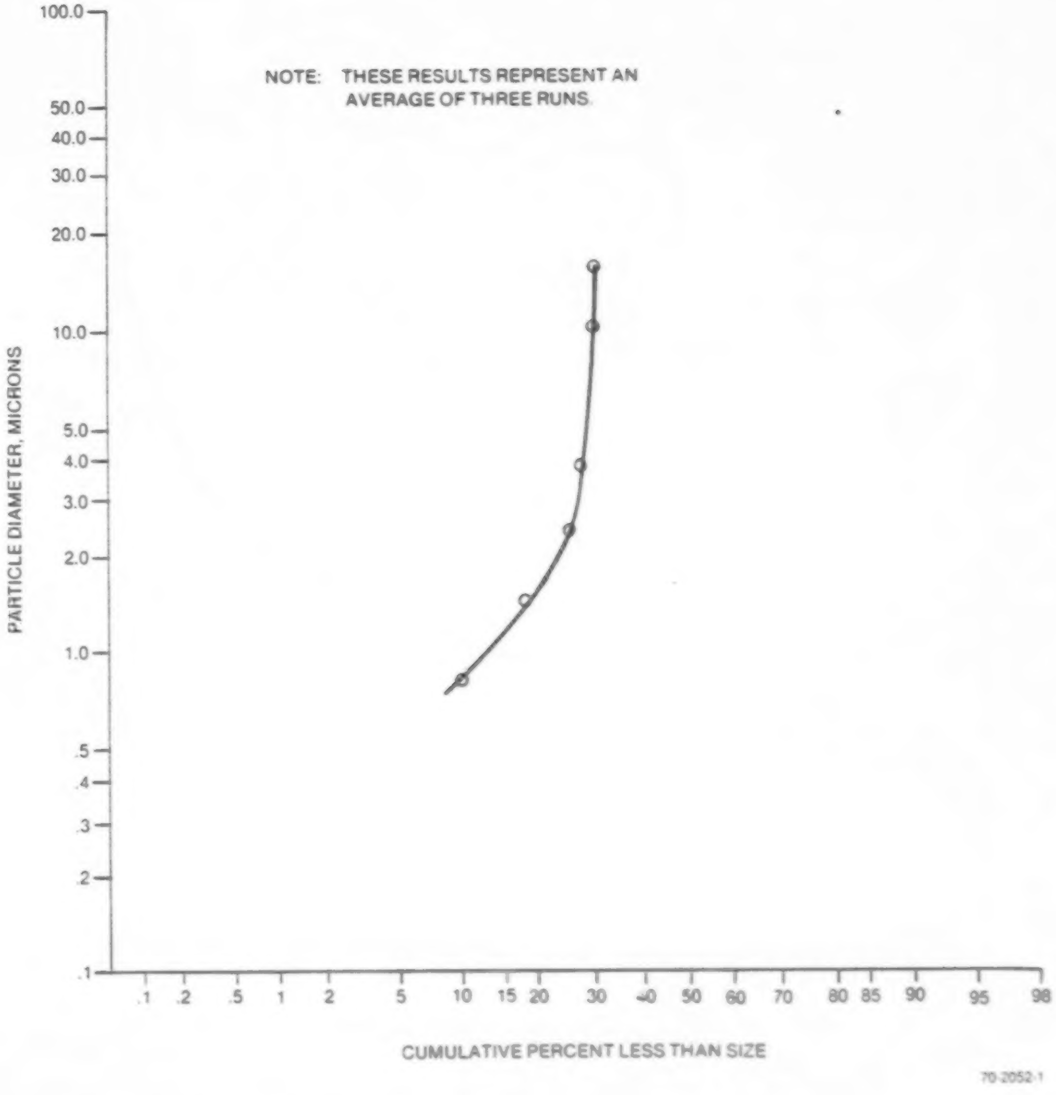


Figure 4-14. Particle size distribution of uncontrolled NFB prill tower exhaust (Plant E).

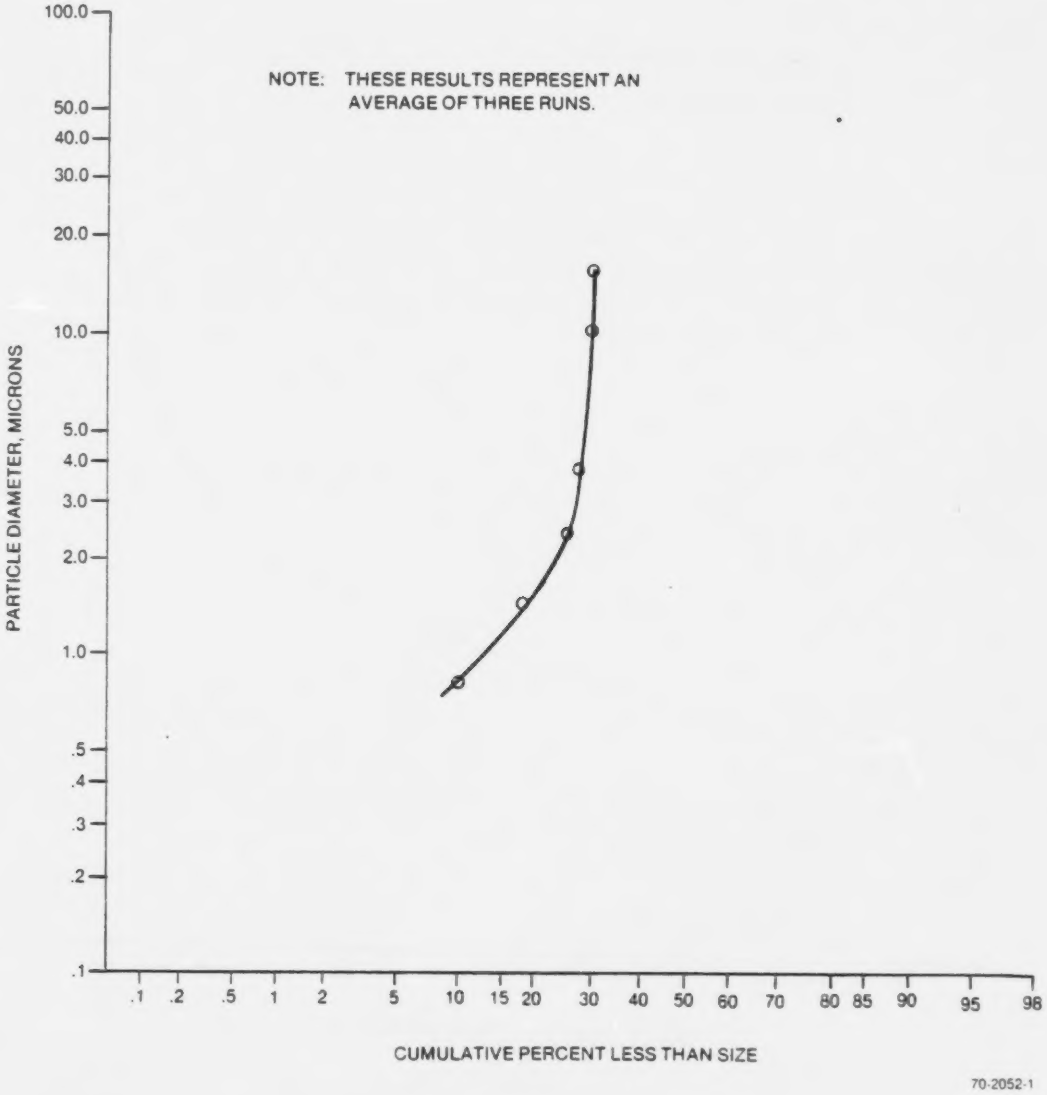


Figure 4-14. Particle size distribution of uncontrolled NFB prill tower exhaust (Plant E).

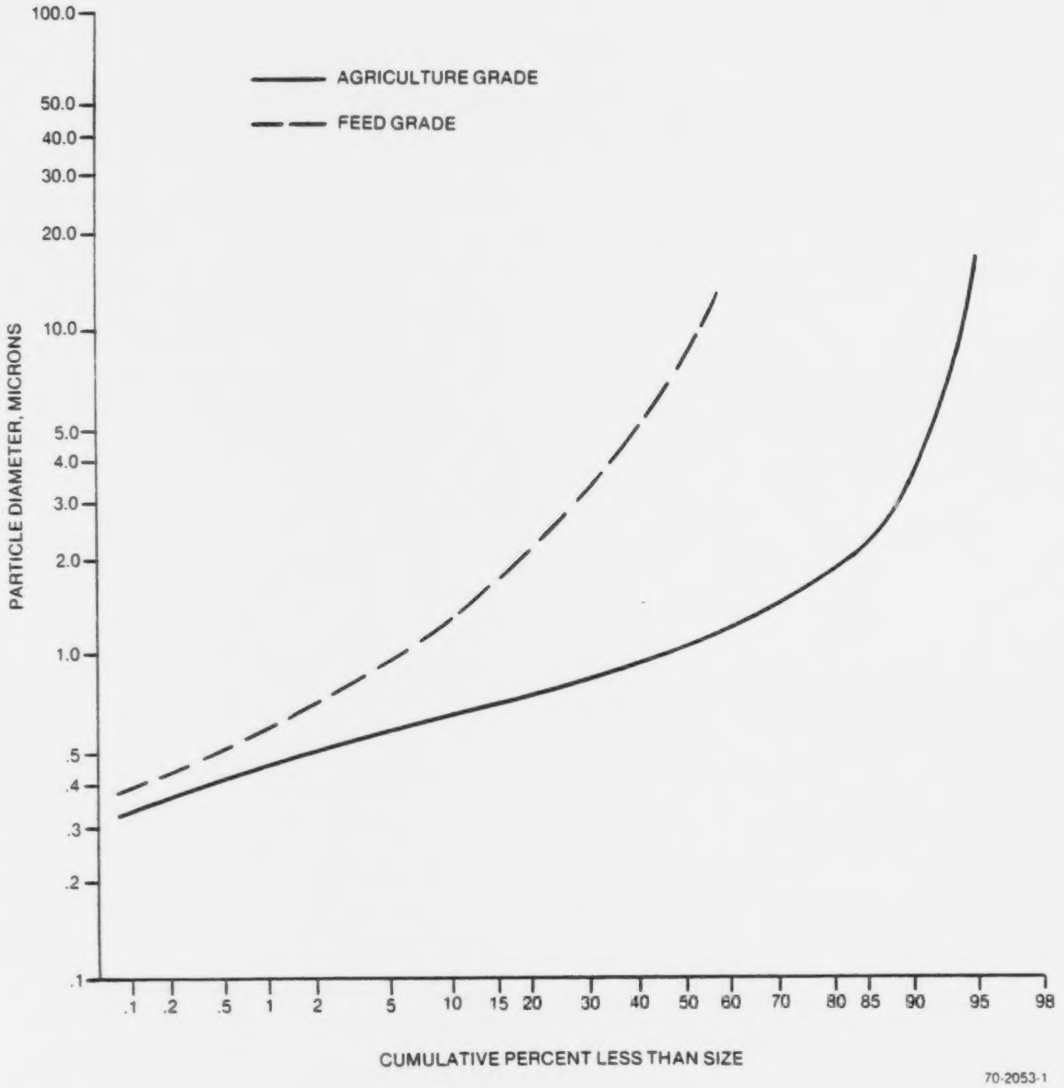


Figure 4-15. Particle size distribution of uncontrolled prill tower exhaust (Plant F - industry data)64

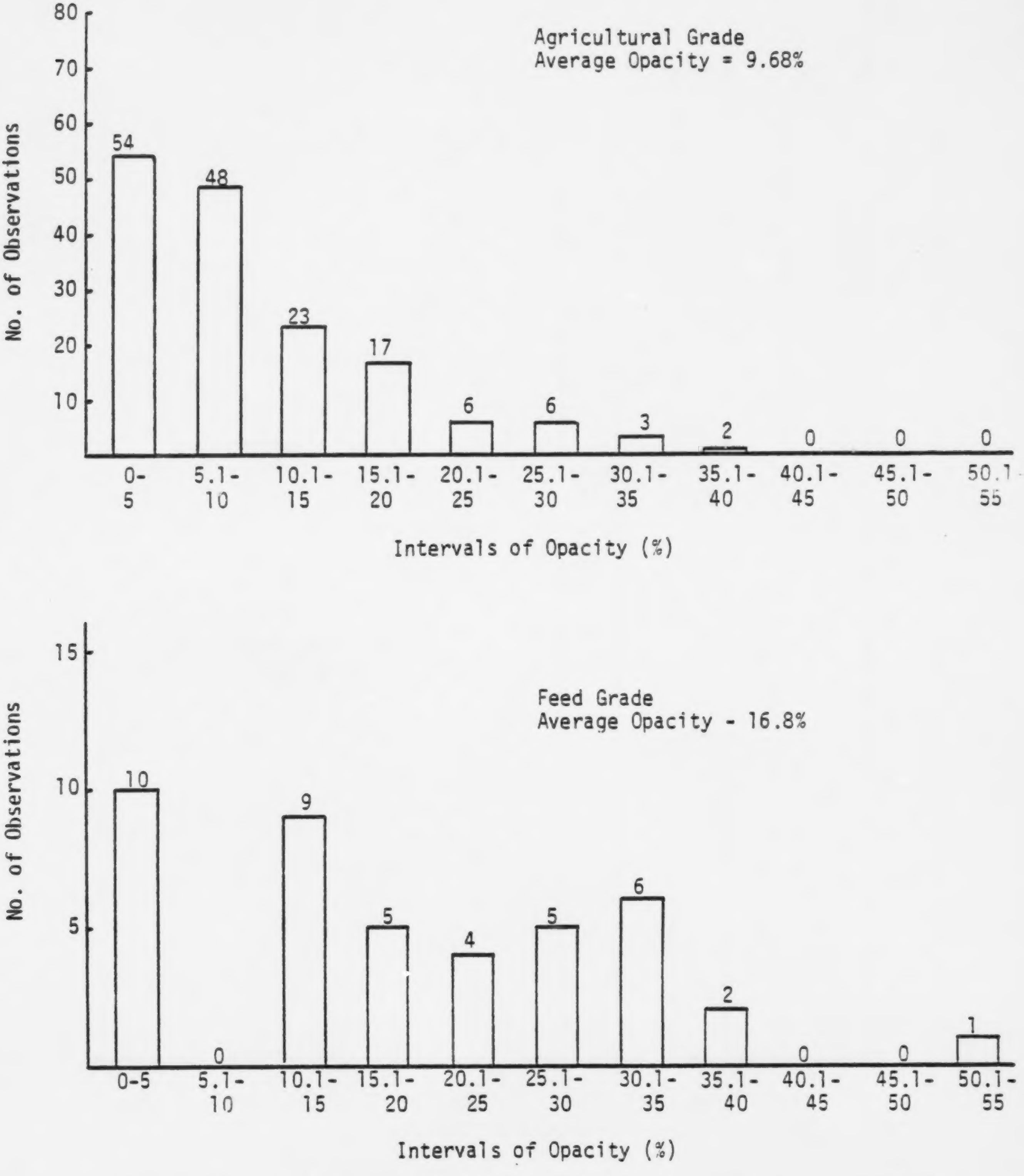


Figure 4-16. Histograms of six minute opacity averages for controlled non-fluidized bed prill tower exhaust, Plant C.

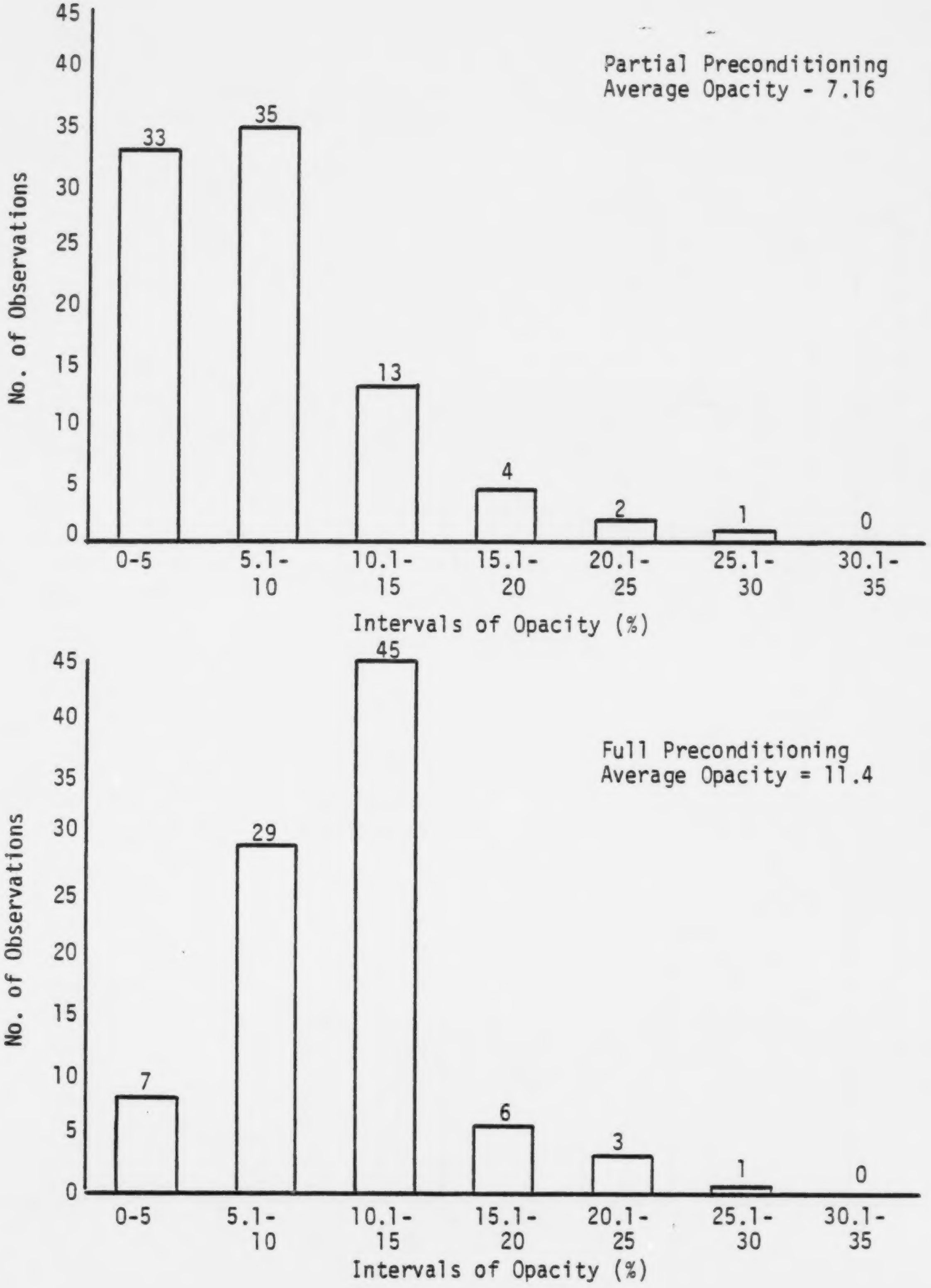


Figure 4-17. Histograms of six minute opacity averages for controlled nonfluidized bed prill tower exhausts, Plant E.

4.3.2 Emission Data for Fluidized Bed Prill Towers

Three fluidized bed prill towers are currently operating in the United States and all are controlled to some degree. Industry data on controlled emission levels at two of the three installations is summarized in Table 4-4.

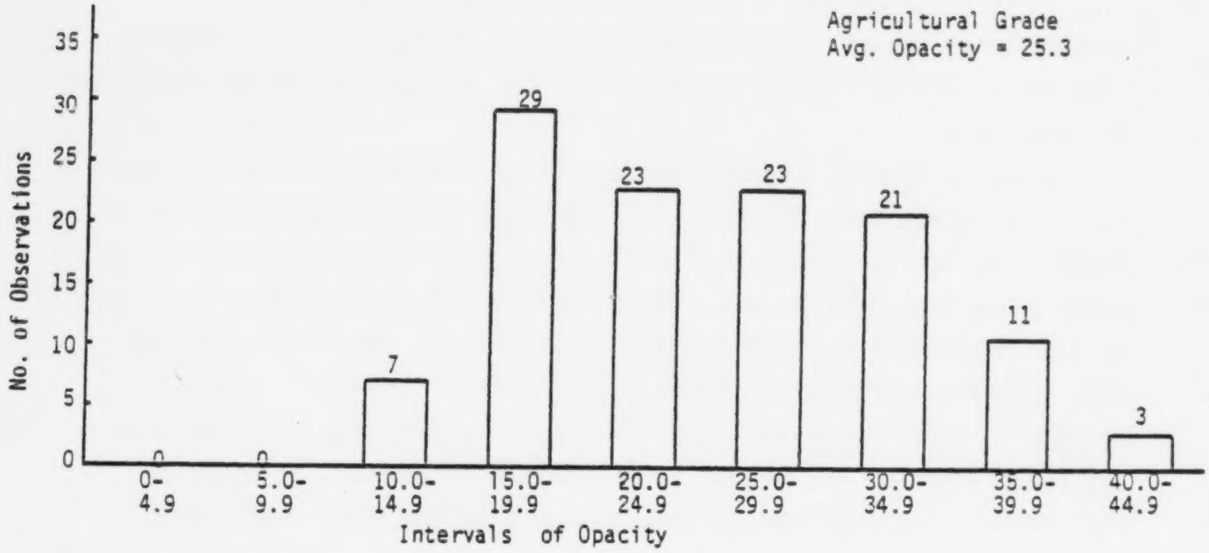
Industry data on uncontrolled emissions from Plant D's prill tower generally agrees with EPA data. EPA tests at Plant D are summarized in Appendix A, Tables A-40 through A-47. Both agricultural grade and feed grade production were tested. These tests involved measurements on two of eight scrubbers operated at this installation. The total emission rate from all operating scrubbers was calculated by factoring each scrubber emission valve by four. This assumes that the tested scrubbers are representative of the remaining untested scrubbers. Velocity and visible emission measurements show this assumption to be reasonable (see Appendix A).

A histogram of the visible emission data collected during the testing at Plant D is shown in Figure 4-18. The distribution of readings changes slightly between agricultural and feed production, and the average opacity is 4.5 percent higher during agricultural grade production.

Particle size distribution information was obtained at Plant D during testing. Two tests (each consisting of three runs) were made for both agricultural and feed grade production. This data is presented in Figure 4-19. In general, feed grade production shows increases in particle sizes over agricultural grade production similar to the trend noted on nonfluidized bed prill towers.

4.3.3 Emission Data for Rotary Drum Granulators

Mass emission tests were conducted by EPA on three drum granulators. At Plant A, granulator "A" was tested twice and granulator "C" was tested once. During granulator "C" testing, a variety of factors which potentially could affect test method accuracy were investigated and no particle size or visible emissions were measured. At Plant B, one test was conducted which included uncontrolled, controlled, visible, and particle size emission measurements.



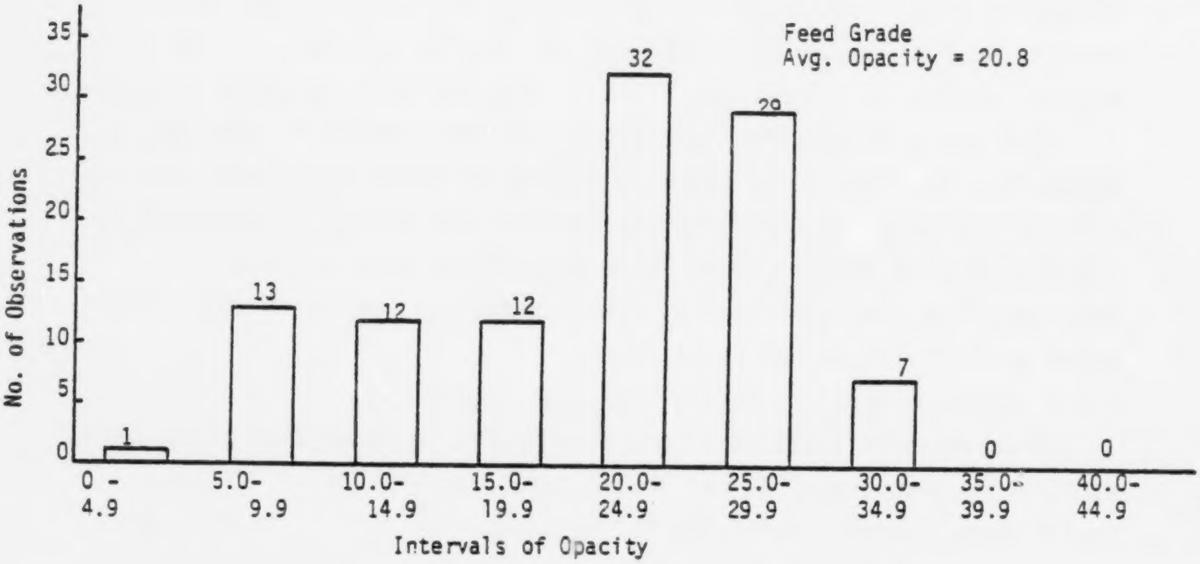


Figure 4-18. Histograms of six-minute opacity averages for controlled FB prill tower exhaust (Plant D).

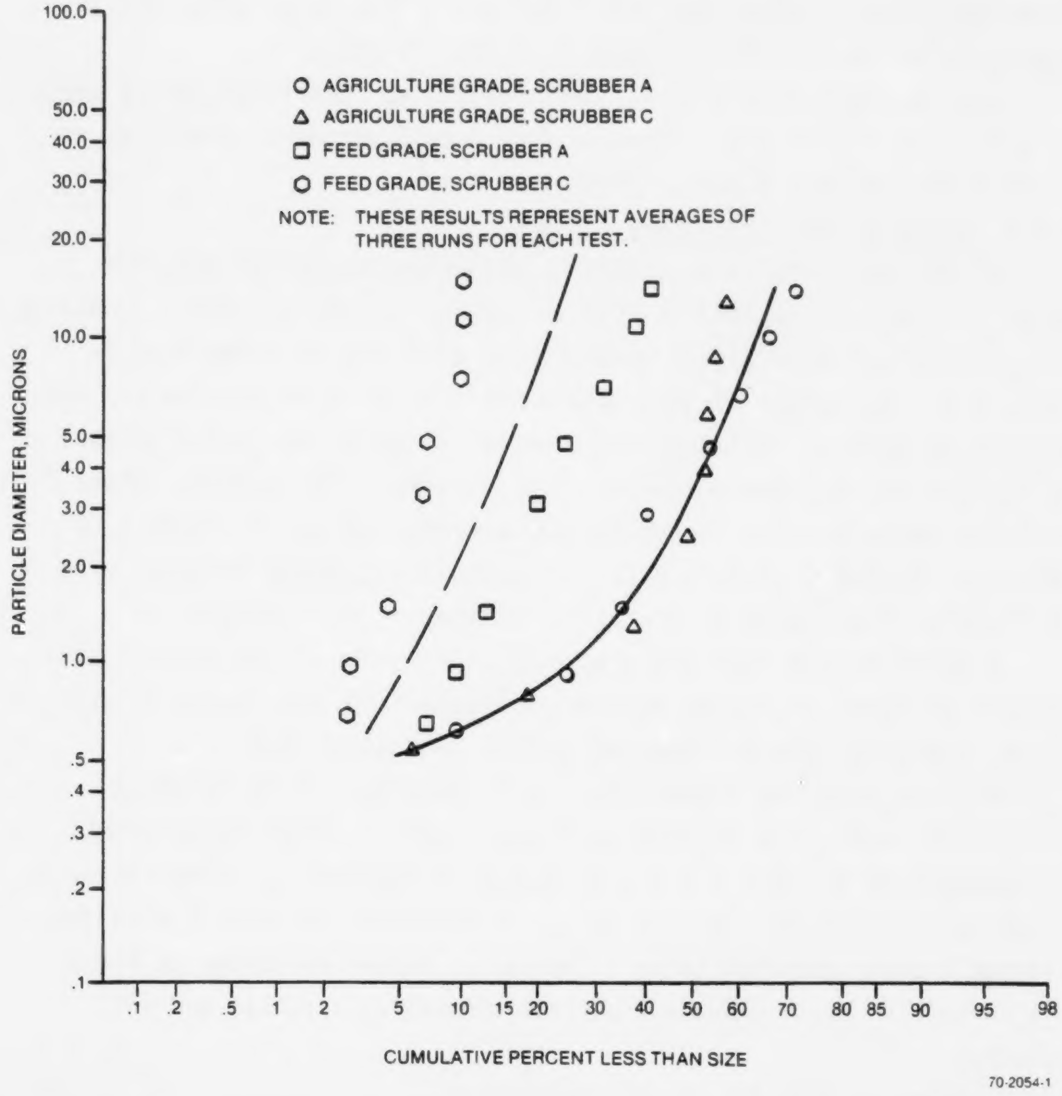


Figure 4-19. Particle size distribution of uncontrolled FB prill tower exhausts (Plant D).

In testing granulator "A" at Plant A, and Plant B very high removal efficiencies (above 99.8 percent) were demonstrated. One reason for the high efficiency of granulator scrubbers is the large particle sizes found in granulator exhausts where several particle size tests were conducted, showing that less than 1 percent of the total emissions in granulator exhausts were less than 5 microns in size.

Opacity measurements on all tests were low. Opacities during tests on granulator "A" at Plant A ranged from 0 to 5 percent. Opacities at Plant B were between 5 and 10 percent.

4.3.4 Emission Data for Rotary Coolers

No EPA test data is available to determine controlled emission rates from any of the devices used to control cooler emissions. Industry has reported emission rates, however, and this data is summarized in Table 4-5. An average of this data results in an emission rate of .035 kg/Mg (.07 lb/ton) EPA tested the uncontrolled rotary cooler exhaust at Plant C and measured emissions of 3.73 kg/Mg (7.45 lb/ton). Plant C personnel have measured controlled cooler emissions of .01 kg/Mg (.02 lb/ton). According to this data, the mechanically aided scrubber used at Plant C is achieving an overall efficiency of 99.7 percent.

A particle size test was also conducted on the uncontrolled cooler exhaust at Plant C. As can be seen in Figure 4-20, the particles are large, with less than 0.3 percent smaller than 10 microns.

Visible emissions measurements were conducted on the scrubber outlets of rotary drum coolers at plants C and E. These measurements are summarized in Table 4-3 and presented in Appendix A. A mechanically aided scrubber is used to control cooler emissions at Plant C with the average opacity reported to be 23 percent. Cooler emissions at Plant E are controlled to an average 3 percent opacity by a packed bed wet scrubber.

4.3.5 Emission Data for Bagging Operations

Mass emission test data are not available for fabric filters controlling emissions from a urea bagging operation. However, regardless of the type, baghouses can attain collection efficiencies greater than 99

TABLE 4-5. SUMMARY OF COOLER CONTROLLED EMISSIONS (INDUSTRY DATA)

Type of Control Device	Model	Plant Where Used	Reported Outlet Emission Rate kg/Mg	(lb/ton)	Reported Pressure Drop KPa	(in. W.G.)
Packed Tower[60]	Buell Flyash	H	.01-.015	(.02-.03)	.25	(1)
Tray Type[61]	Sly	I	.1	(.2)	Not Available	
Packed Tower[62]	American Air Filter, Hydrofilter	E	.02	(.04)	.25	(10)
Mechanically[63] Aided	American Air Filter, Rotoclone Type W	C	.01	(.02)	Not Applicable[a]	

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[a] Mechanically aided scrubber supplies power through intergral rotor.

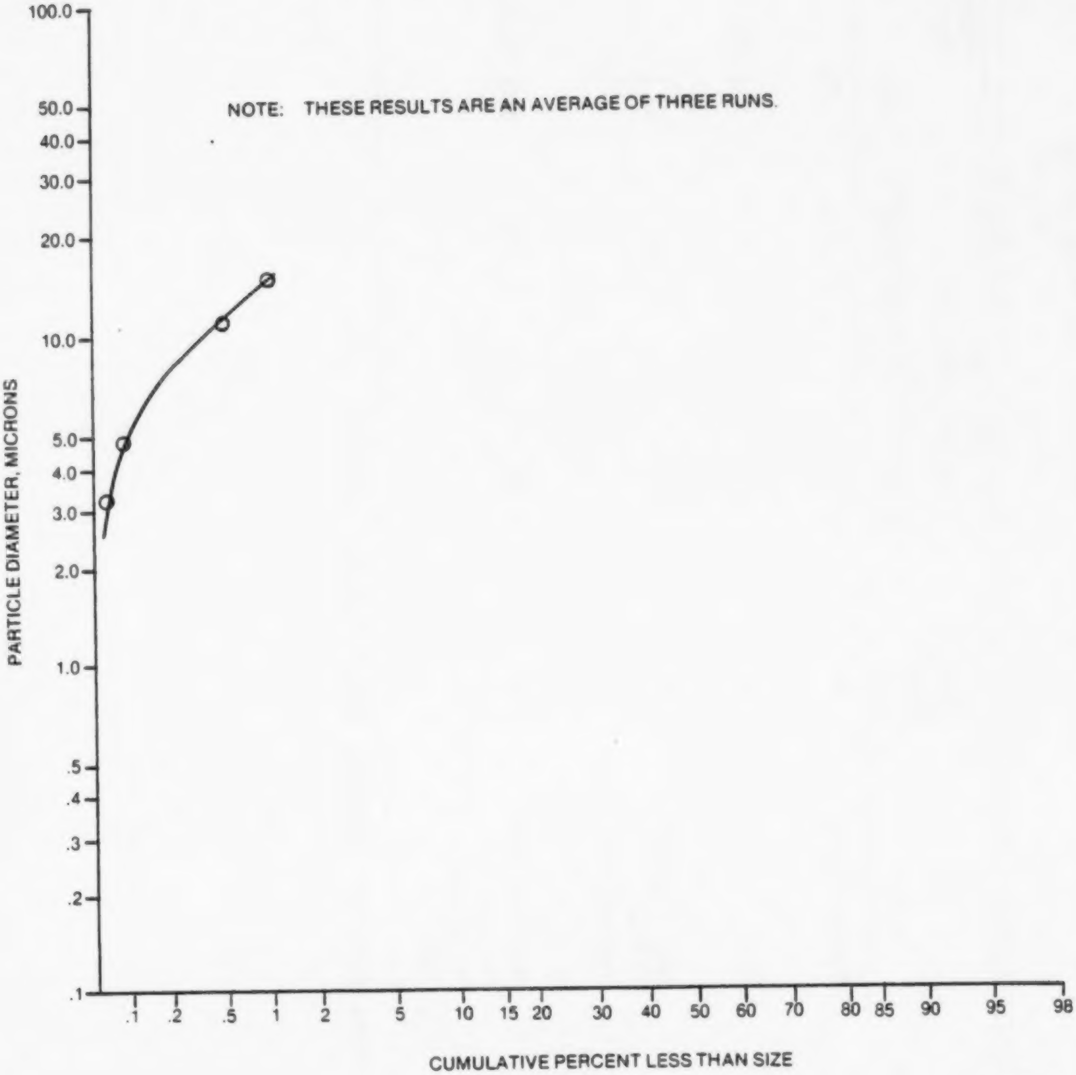


Figure 4-20. Particle size distribution of uncontrolled cooler exhaust (Plant C).

percent even on submicron particle sizes.[32] Testing conducted by EPA on baghouses used to control emissions in the non-metallic mineral industry demonstrated efficiencies of 99.8 percent or better with no visible emissions (zero percent opacity).[33,34,35]

Opacity measurements were made at Plant D to determine visible emission levels from fabric filter controlled bagging operations. Visible emissions were usually nonexistant. The average opacity during this test was .05 percent.

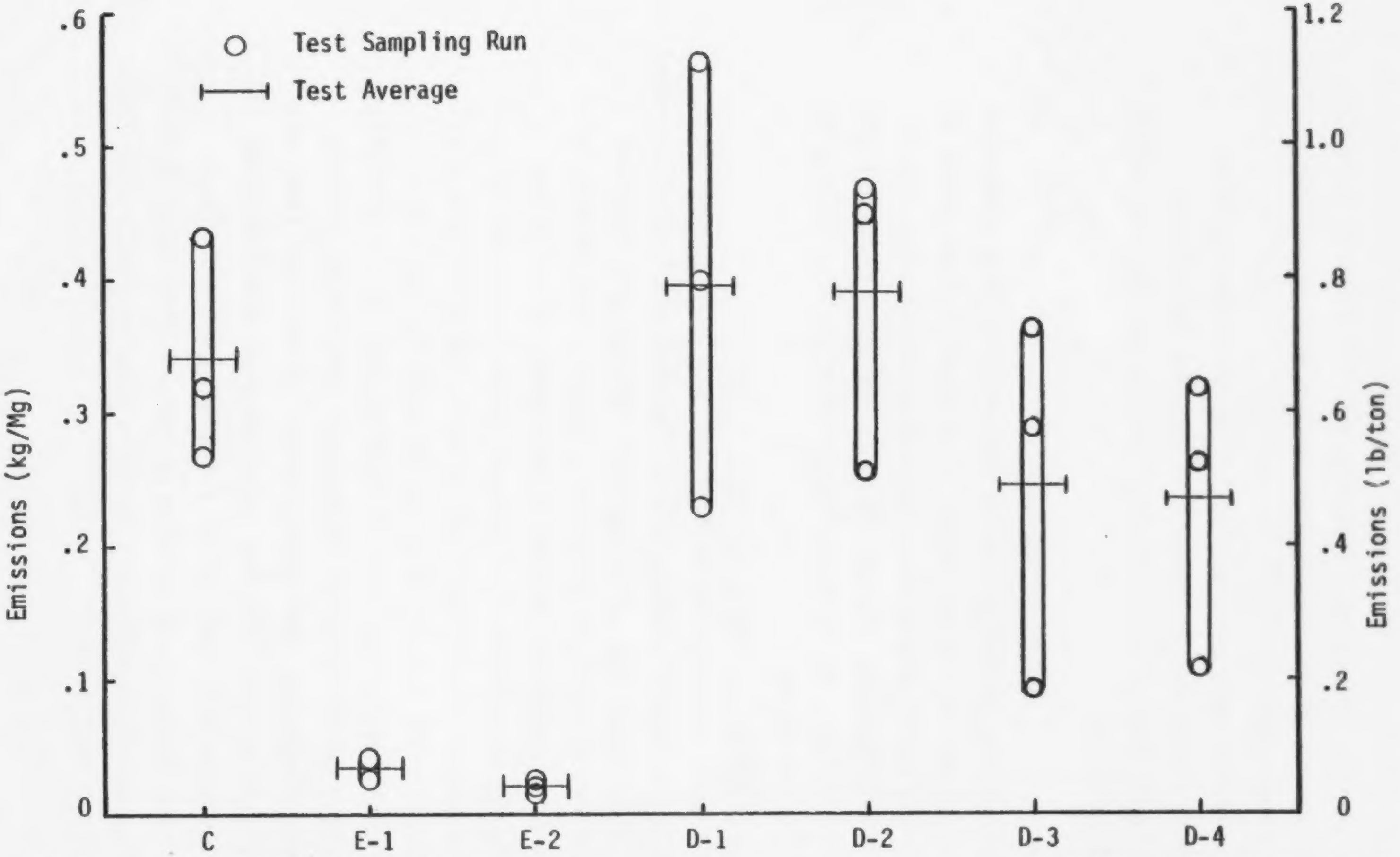
4.4 EVALUATION OF CONTROL DEVICE PERFORMANCE

This section presents an evaluation of the emission data presented in Section 4.3. This evaluation includes: 1) a general examination of the data to determine relative accuracy and representativeness, and 2) an assessment of the effects of changes in emission characteristics on control device performance. As in the previous section, the discussion is arranged by emission source.

4.4.1 Nonfluidized Bed Prill Towers

Available EPA test data consist of tests of nonfluidized bed prill towers (producing agricultural grade urea) at Plants C and E as illustrated in Figure 4-21. Plant C was tested during both agricultural and feed grade production in April, 1979; however, the analysis was improperly conducted and the data unusable. During a subsequent retest it was possible to test emissions during agricultural grade production only. At Plant E, feed grade emissions could not be measured since this plant produces agricultural grade only. Thus, no EPA emission data for nonfluidized bed prill towers producing feed grade product is available.

The two scrubber outlet emission tests (each consisting of three test runs) at Plant E measured the lowest controlled emission level of any prill tower tested by EPA. The two tests measured emission rates of .0320 kg/Mg and .0220 kg/Mg (.0641 lb/ton and .0440 lb/ton). The wetted fibrous filter demonstrated an average removal efficiency of 98.7 percent based on uncontrolled emissions measured simultaneously with the first outlet emission test.



Test C:	Plant C, nonfluidized bed, agricultural grade packed bed scrubber
Test E-1:	Plant E, nonfluidized bed, agricultural grade, wetted fibrous filter, partial preconditioning
Test E-2:	Same as E-1 except full preconditioning
Test D-1:	Plant D, fluidized bed, agricultural grade, entrainment scrubber "A"
Test D-2:	Same as D-1 except scrubber "C"
Test D-3:	Same as D-1 except feed grade
Test D-4:	Same as D-2 except feed grade

Figure 4-21. Emission levels from controlled prill tower, EPA tests

This removal efficiency is confirmed by the performance curve provided by the control device manufacturer. This fractional efficiency curve, based on pilot plant evaluations of a prototype wetted fibrous filter unit and presented earlier as Figure 4-10, gives the particle removal efficiencies for various size ranges of particles. Using these removal efficiencies and the uncontrolled particle size distribution measured at Plant E (Figure 4-14), a removal efficiency of 98.4 percent is predicted. This compares favorably with the 98.7 percent actually measured.

An independent test conducted by company personnel at Plant E, under conditions similar to those during EPA testing, confirmed the results obtained during EPA testing. They measured controlled emissions of .0271 kg/Mg (.0541 lb/ton) (see Table 4-4), which is very close to the EPA measured emissions.

A comparison of controlled emissions between Plant E and Plant C reveals considerably higher emissions at Plant C. These higher emissions are believed to be the results of two factors. First, the wetted fibrous filter used at Plant E operates at a much higher pressure drop and is specifically designed for control of particles less than 1 micron.[36] In contrast, packed bed scrubbers are typically used for control of gaseous pollutants or in situations where the particles tend to be larger than 5 micron. Secondly, the prill tower exhaust at Plant C contains a much higher percentage of fine particles. A comparison of the internal air velocities between the two prill towers reveals considerable differences which might account for the change in particle size. The velocity in Plant C's tower is approximately .365 m/s (1.2 ft/sec),[37] while the velocity in Plant E's tower is approximately 1.29 m/s (4.24 ft/sec).[38] Higher airflow increases the entrainment of particulates and may also increase the generation of small particles. A higher tower airflow would increase the turbulence near the molten prill resulting in the formation of small, solid urea particles.

EPA tests are usually conducted on facilities which appear to be using the best available control technology. Plant C was selected for testing because at the time of the test, it was the only plant known to operate a nonfluidized bed prill tower which offered reasonable sampling locations. Mistakes in the sample analysis during the first test at Plant C resulted in erroneous data. By the time it was conclusively determined that this data was faulty, the test at Plant E was in the planning stage. Therefore, the retest at Plant C was limited to the minimum necessary to confirm the errors in the initial test. Therefore, only controlled emissions during agricultural grade production were retested.

As mentioned earlier, no EPA mass emission data is available to quantify either controlled or uncontrolled nonfluidized bed prill tower emissions during feed grade production. However, a number of factors infer that feed grade emissions are easier to control compared to agricultural grade emissions. First, all available particle size data shows that larger particles are generated during feed grade production. Larger particles are more effectively removed by control systems than small particles. A comparison of the size distributions measured at Plant C during both grades of production (Figure 4-13) shows a clear shift toward larger particles during feed grade production. This shift is confirmed by a similar shift noted for fluidized bed prill towers (Figure 4-10) and industry particle size tests of a nonfluidized bed prill tower (Figure 4-15). Secondly, available data indicates feed grade emissions are probably lower than agricultural grade emissions. The only direct comparison between uncontrolled emission rates during both types of production using a nonfluidized bed prill tower is industry tests at Plant F (see Table 3-3). These tests measured 15 percent higher uncontrolled emissions during feed grade production. However, due to problems frequently encountered in testing prill towers and differences in test methods, industry data is difficult to quantify. The particle size data from this same plant indicates the control device efficiency would be improved because of the larger feed grade particulate. Increased efficiency would more than compensate for the slightly higher uncontrolled emissions during feed grade production. EPA tests of a fluidized bed prill tower showed a 40 percent decrease in emissions in switching from agricultural to feed grade production. Since both types of prill towers are generally operated in a similar manner, with similar reductions in airflow during feed grade production, this decrease in emissions is believed to be typical for prill towers producing both product grades.

Another variable believed to effect the uncontrolled emission characteristics of nonfluidized bed prill towers is ambient temperature. Available data indicates that colder temperatures promote the formation of smaller particles in the prill tower exhaust.[39,40] Since smaller particles are more difficult to remove, the efficiency of control devices used on prill towers tends to decrease with lower temperatures. This can lead to higher controlled emission levels while prill towers are operated during cold weather.

The physical mechanism responsible for this shift toward smaller particles is not clearly understood. Available industry and EPA particle size data indicates the existence of two distinct populations of particles in prill tower exhausts. One population is greater than 5 micron in size and is composed of small micro prills and prill fragments. This population is believed to be formed as the molten urea separates into droplets at the melt distributor and as the semi-solid prills strike each other and the prill tower walls. The second population is smaller than 5 micron and is believed to result from the condensation of urea vapor into small crystals. Microscopic examination of the small particles reveals a crystalline structure, similar in appearance to a snowflake.[41] Urea vapor pressure data indicates that sufficient urea is present in the vapor state in a prill tower to account for the small particle emissions.[42] The growth of urea crystals is directly affected by the rate at which the urea vapor is cooled, while this rate is directly affected by the temperature of the air drawn into the prill tower. During cold weather the vapor is quickly cooled from melt temperature to the exhaust duct temperature, while in warm weather the transition is more gradual. Rapid cooling does not allow time for the formation of larger crystals in the saturated urea vapor. Instead, many small crystals are formed as the saturated urea vapor cools.

Personnel at Plant E conducted fifteen particle size tests during a control device evaluation program.[43] This program involved the ducting of a slipstream from the prill tower exhaust to a ground mounted sampling location. Because the sampling technique did not account for segregation of particles within the slipstream due to flow direction changes caused by the ducting, only the fraction of particles 5 micron in size are in size considered in the following discussion. The effect of this exclusion on the final controlled emission levels presented later is negligible since prill tower control devices typically remove nearly all particles of size larger than 5 micron.

Ambient temperature during these fifteen tests ranged from 27 degrees F to 70 degrees F. Histograms of the two tests representing the highest and lowest temperatures are presented in Figure 4-21 and illustrate the increased fraction of particles in the smaller size ranges during cold ambient temperatures. This general trend is evident in all fifteen tests. Figure 4-22 presents a plot of mean particle size vs. ambient temperature for all fifteen tests. Although some scatter is evident, there is clear indication that temperature influences the size of particles in prill tower exhausts.

The effect of this shift in particle size on the efficiency of the wetted fibrous filter scrubber is illustrated in Figure 4-23. Two approaches were used in determining this trend. The first approach involves using each of the fifteen particle size tests in conjunction with the fractional efficiency data presented earlier in Table 4-13 to predict the efficiency for each specific particle size distribution. The individual data points in Figure 4-23 represent this approach. The second approach, represented by the solid line in Figure 4-23, involves assuming a log-normal distribution for the sub 5 micron particles in prill tower exhausts. Nearly all fifteen actual particle size distributions fit the log-normal distribution. Furthermore, several authors indicate that particle sizes are frequently log-normally distributed.[44,45,64]

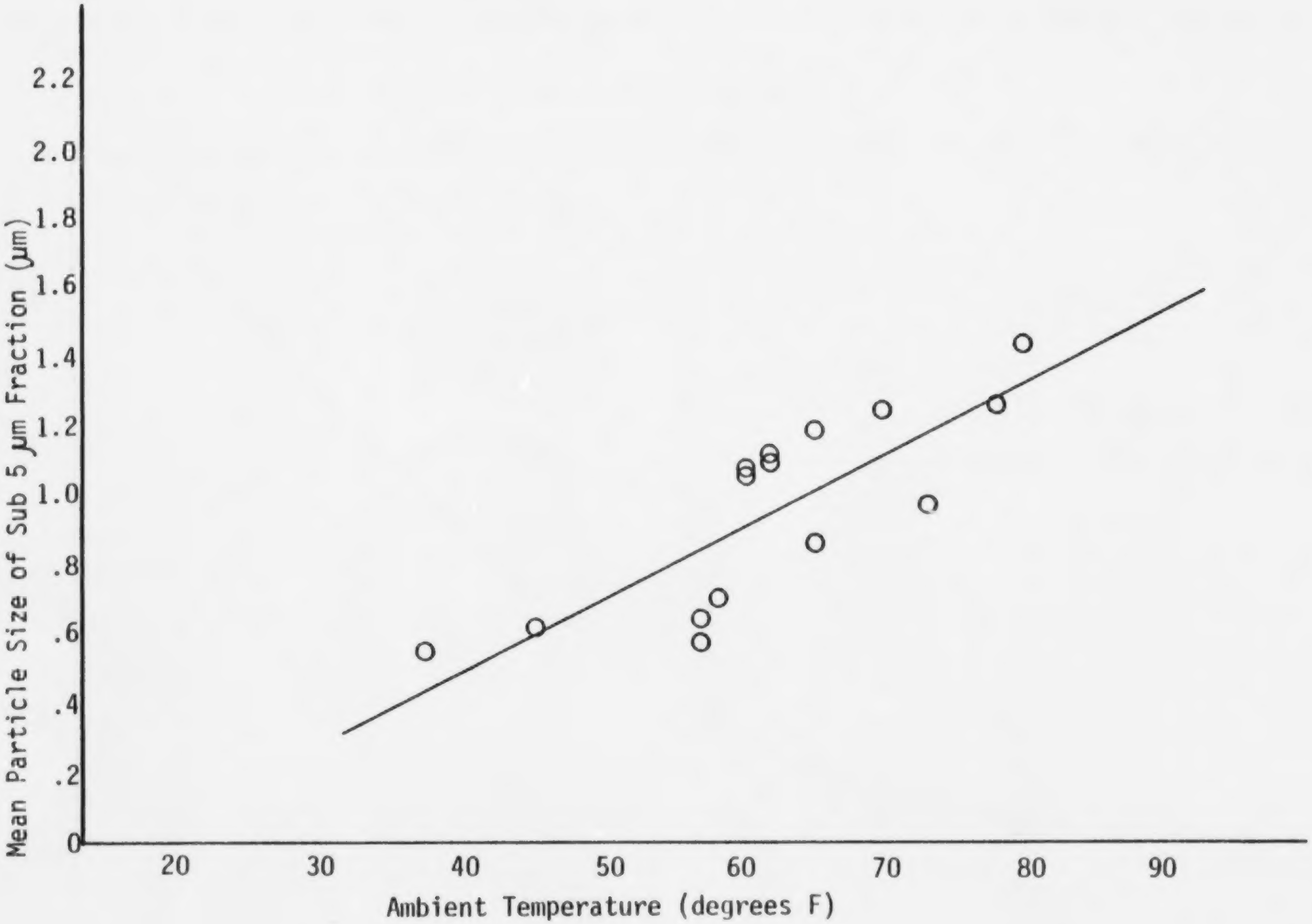


Figure 4-22 Variation in particle size (sub 5 μm mean) with respect to ambient temperature (industry data)

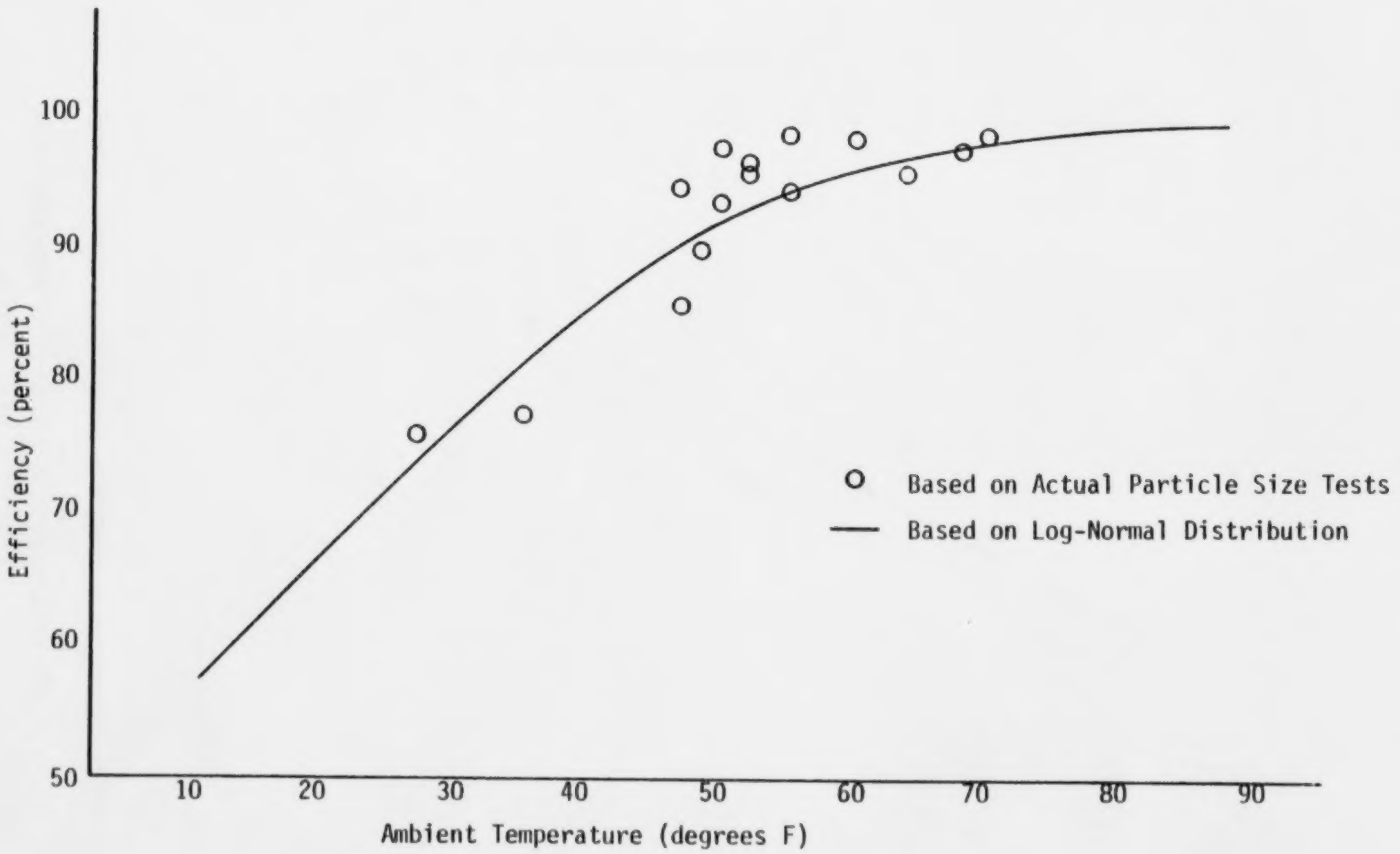


Figure 4- 23. Efficiency of wetted fibrous filter as a function of ambient temperature

With this assumption, it is possible to calculate the particle size distribution for any temperature by varying the mean in accordance with the trend line in Figure 4-22.

The preceding discussion has centered on the effect of temperature on particle sizes. Temperature may also affect the quantity of emissions. Particle concentration data obtained during the fifteen particle size tests at Plant E shows that concentration of particles in the prill tower exhaust is relatively constant with respect to temperature at approximately .039 g/m^3 (.017 gr/acfm). However, prill tower operators typically cut back airflows during cold weather conditions to save fan power since less of the colder air is required for adequate cooling of the prills. From heat transfer considerations, it is possible to predict this cutback. The results of these calculations are presented in Figure 4-24 and agree, in general, with conversations with industry.[65]

Finally, Figure 4-25 presents estimated outlet emissions as a function of the ambient temperature. The prill tower configuration at Plant E was used as a basis for this estimate. Once again, the data points represent actual particle size tests while the trend line was derived through the use of the log-normal distribution model. This plot indicates a considerable increase in controlled emissions as temperature drops.

4.4.2 Fluidized Bed Prill Towers

Controlled and uncontrolled emissions during both agricultural and feed grade production were tested by EPA at the fluidized bed prill tower at Plant D and are illustrated in Figure 4-21. Emissions of .392 kg/Mg (.785 lb/ton) and .240 kg/Mg (.479 lb/ton) were measured during agricultural grade and feed production respectively. Control device efficiency in both tests was approximately 86 percent. The measured efficiencies confirm efficiencies predicted by particle size data and efficiency curves for the entrainment scrubbers.

A similar shift toward smaller particles during cold weather might be expected to occur in fluidized bed prill towers as discussed for nonfluidized bed prill towers. At present, it is impossible to quantify

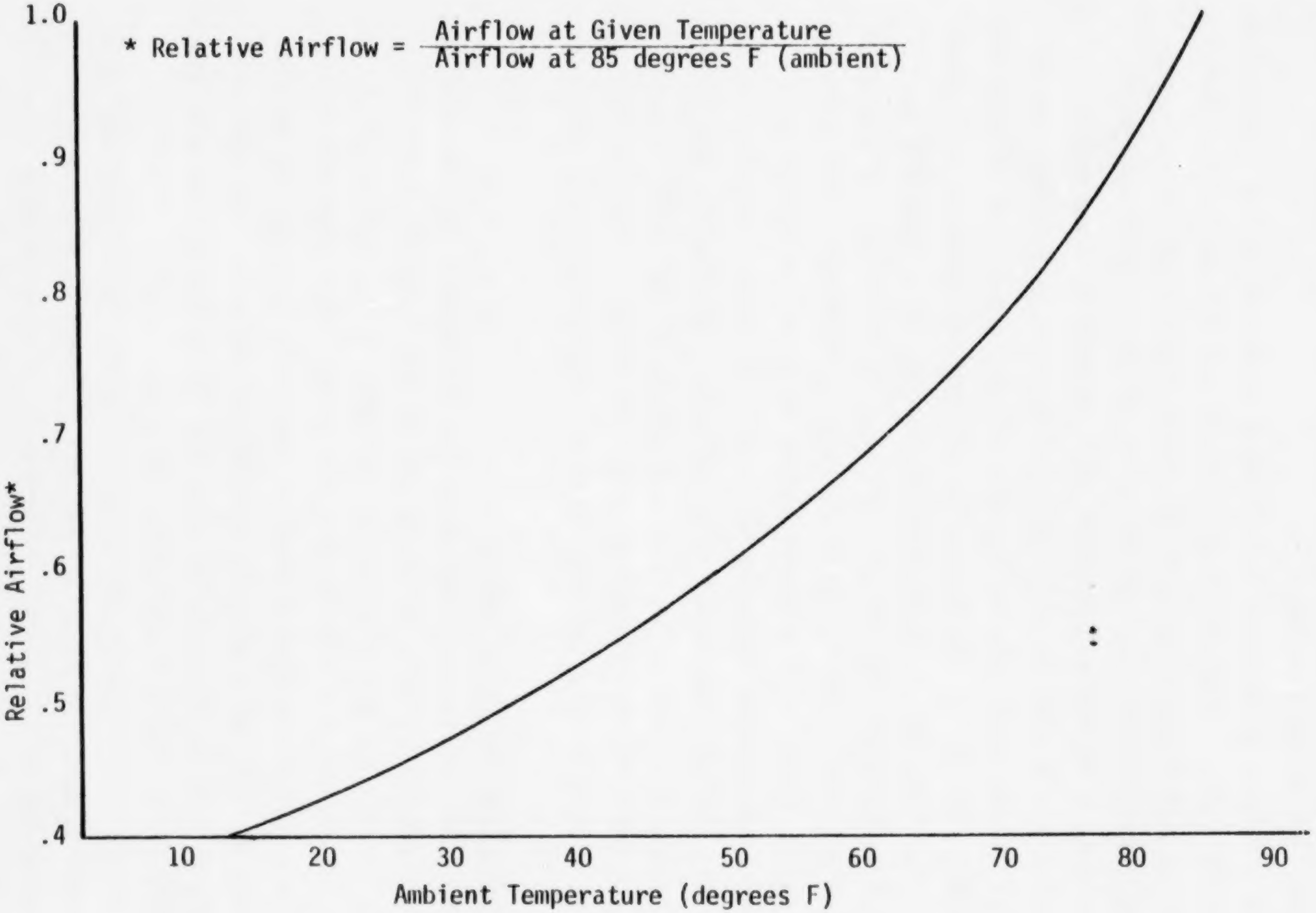


Figure 4- 24. Estimated airflow cutback as a function of ambient temperature

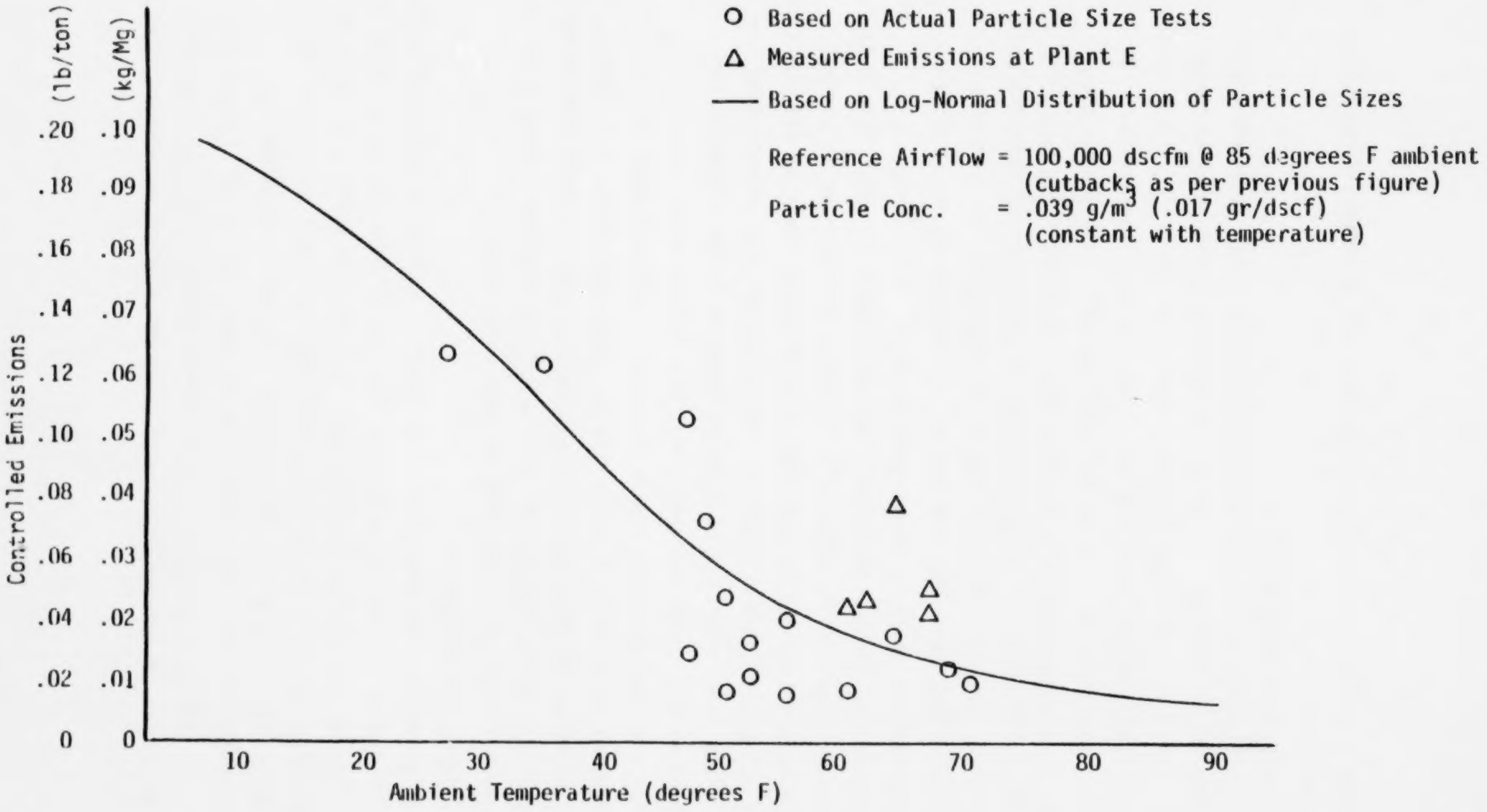


Figure 4-25. Variation in controlled nonfluidized prill tower emissions with respect to ambient temperature

to quantify a shift since particle size data for different temperatures is not available.

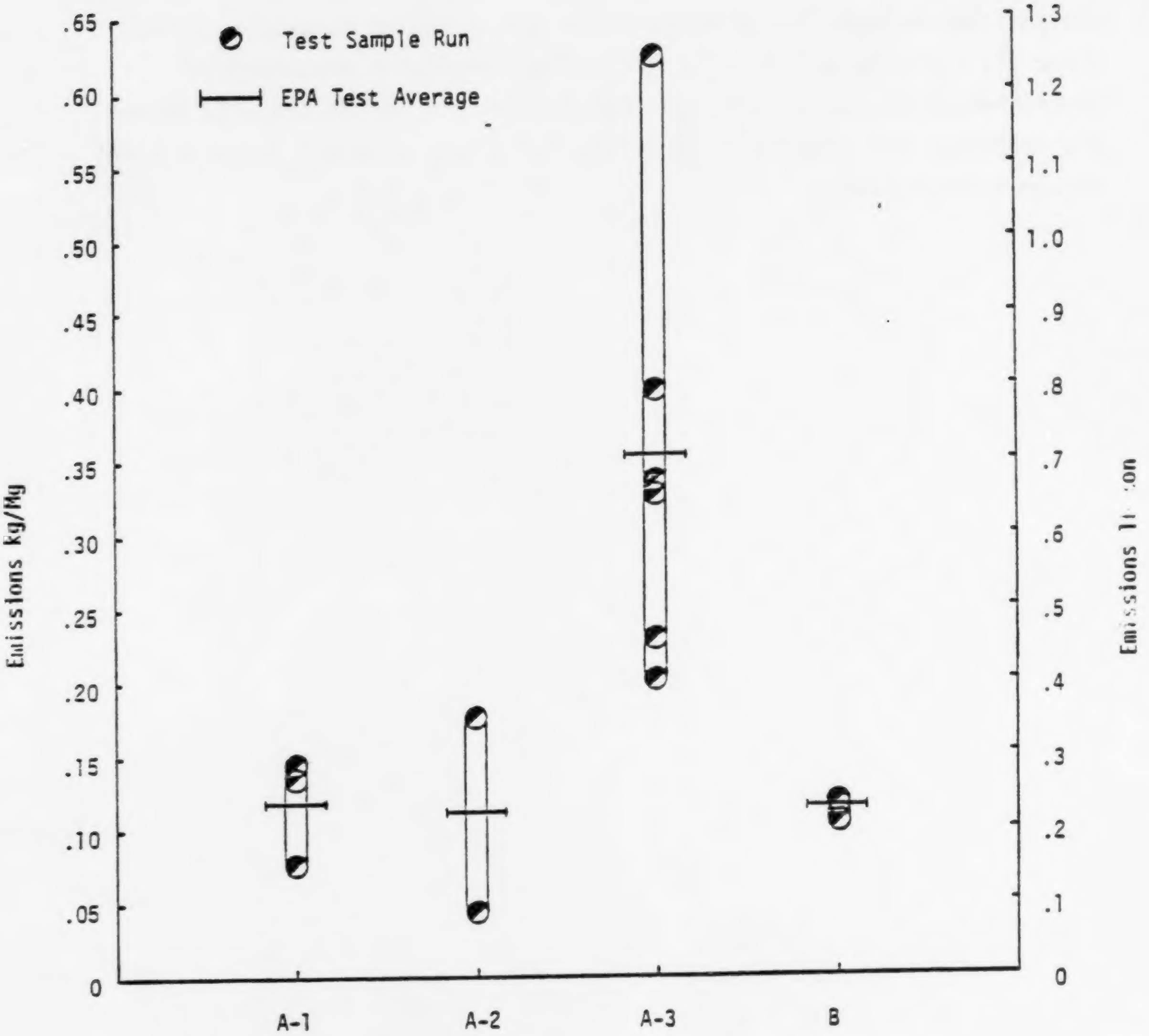
4.4.3 Rotary Drum Granulators

Four EPA tests of three granulator/scrubber units at Plant A are illustrated in Figure 4-26. Two of these tests (granulator scrubber unit "A") measured controlled emission levels of .119 kg/Mg (.238 lb/ton), .111 kg/Mg (.221 lb/ton), and the third test (granulator/scrubber "B" had similar emissions of .114 kg/Mg (.228 lb/ton). The fourth test (granulator/scrubber unit "C") however, measured controlled emissions of .378 kg/Mg (.755 lb/ton). Unfortunately, no uncontrolled emission data are available for this test and thus it is impossible to determine whether the higher emissions are due to differences in uncontrolled emission characteristics or lower control device efficiency.

According to Plant A personnel, the granulator/scrubber Unit A is virtually identical to the Unit C.[66] However, differences in visible emissions between the units have been noticed since start-up with Unit C emitting a plume of higher opacity. The plant has not investigated the problem since both units are well below state emission standards and have a high rate of urea recovery (99.9 and 99.7 percent recovery). Concerning the reason(s) for the difference, plant personnel indicate lower scrubber efficiency is most likely. They speculated that the internal scrubber baffles may be misaligned. Based on these observations, it appears that units "A" and "B" at Plant A are representative of a granulator/scrubber unit operating at peak efficiency.

4.4.4 Rotary Drum Coolers

Controlled mass emission data submitted by several plants operating coolers indicates controlled emissions that range from .01 to .1 kg/Mg (.02 to .2 lb/ton) with an average emission of .035 kg/Mg (.07 lb/ton). These emission levels are generally confirmed by predicted controlled emissions using uncontrolled EPA emission data and control device performance curves. A single tray type scrubber operating at a pressure drop of .375 kPa (1.5 in. W.G.) would remove approximately 98.9 percent of the particles in the cooler exhaust. An entrainment scrubber operating



Test A-1: Plant A, Scrubber A, Test 1
Test A-2: Plant A, Scrubber A, Test 2
Test A-3: Plant A, Scrubber C
Test B: Plant B, Scrubber B

Figure 4-26. Emission levels from controlled granulator exhausts.

at an overall 1.25 to 1.50 kPa (5 to 6 in. W.G.) pressure drop would perform at approximately 99.6 percent efficiency. These high efficiencies are possible because of the large particles in cooler exhausts. Using these efficiencies and EPA uncontrolled mass emission measurements, controlled emissions of .043 and .016 kg/Mg (.086 lb/ton and .031 lb/ton) are estimated for a cooler controlled with a tray type and an entrainment scrubber respectively.

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5.0 MODEL PLANTS AND CONTROL ALTERNATIVES

Model urea plants and control alternatives are defined in this chapter. The model plants are chosen to be representative of solids producing plants in the urea industry. The model plants and control alternatives are used in subsequent chapters as the basis for analysis of the environmental and economic impacts associated with control of particulate emissions from sources in the urea industry.

Section 5.1 describes the model plants in terms of process configuration, plant capacity, operating hours, raw material requirements, and utility requirements. Section 5.2 defines the existing level of control (ELOC) on each emission source. Section 5.3 describes the control options for each source, and Section 5.4 defines the control alternatives for each model plant.

5.1 MODEL PLANTS

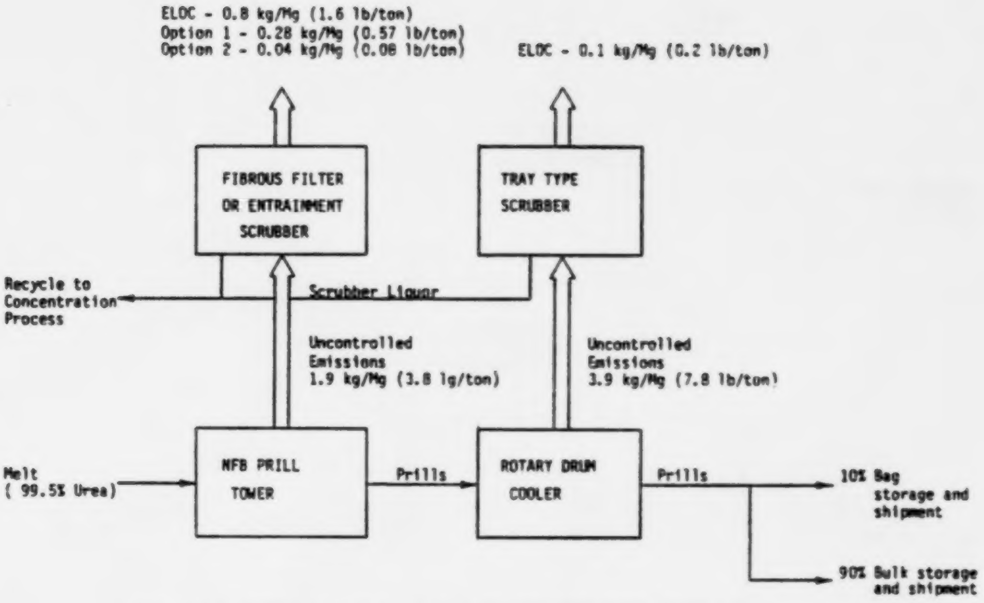
Process operations used in urea manufacturing include urea solution production, solution concentration, solids formation, solids finishing and solids handling. Urea plants differ in process configuration, plant capacity, and product type. In order to account for this variability, ten model plants were selected based on the present mix of process configurations and plant sizes in the industry. Table 5-1 identifies the solids formation process, plant capacity, and product type for each model plant. Process and control device flow diagrams for each model plant are presented in Figures 5-1 and 5-2. Further information concerning the control options and emission characteristics of each model plant is contained in Section 5.2.

5.1.1 Process Configurations

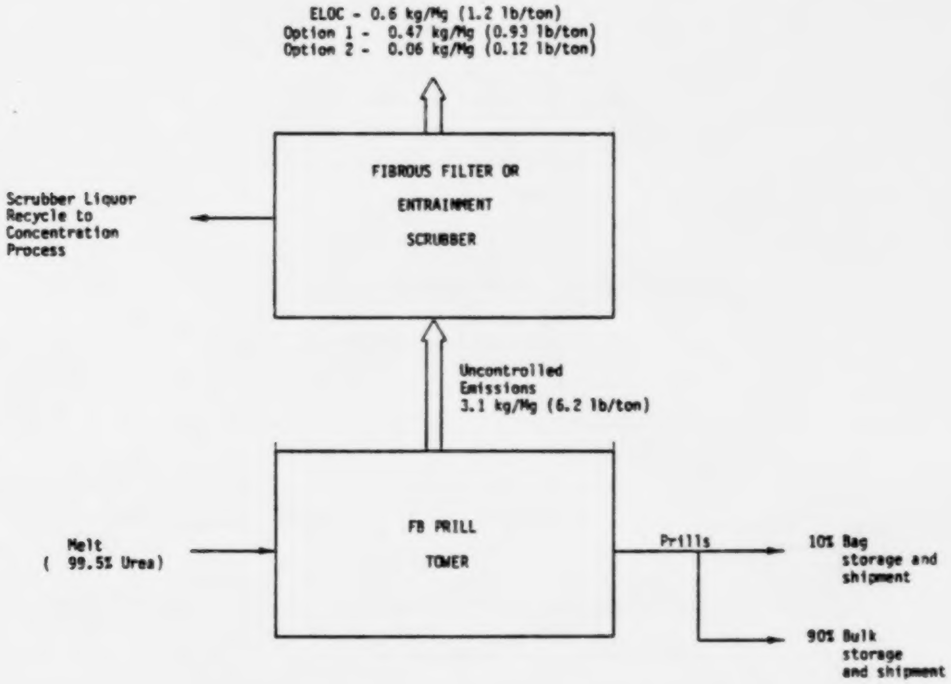
Four solids production techniques are currently in use in the urea industry: nonfluidized bed prilling, fluidized bed prilling, drum granulation, and pan granulation. However, only one pan granulator is

TABLE 5-1. UREA MODEL PLANTS

Model No.	Plant Capacity Mg/day (ton/day)	Configuration	Emission Sources	Process Diagram Figure	Emission Characteristics Table
1	182 (200)	Non-fluidized prill tower plant producing agricultural grade prills. Supplementary cooling required.	Prill Tower Cooler	5-1(a)	5-7
2	726 (800)				5-8
3	1090 (1200)				5-9
4	182 (200)	Fluidized bed prill tower plant producing agricultural grade prills. No supplementary cooling required.	Prill Tower	5-1(b)	5-10
5	726 (800)				5-11
6	1090 (1200)				5-12
7	182 (200)	Same as 4 except feed grade.	Prill Tower	5-2(a)	5-13
8	363 (400)	Granulation Plant	Granulator	5-2	5-14
9	726 (800)				5-15
10	1090 (1200)				5-16

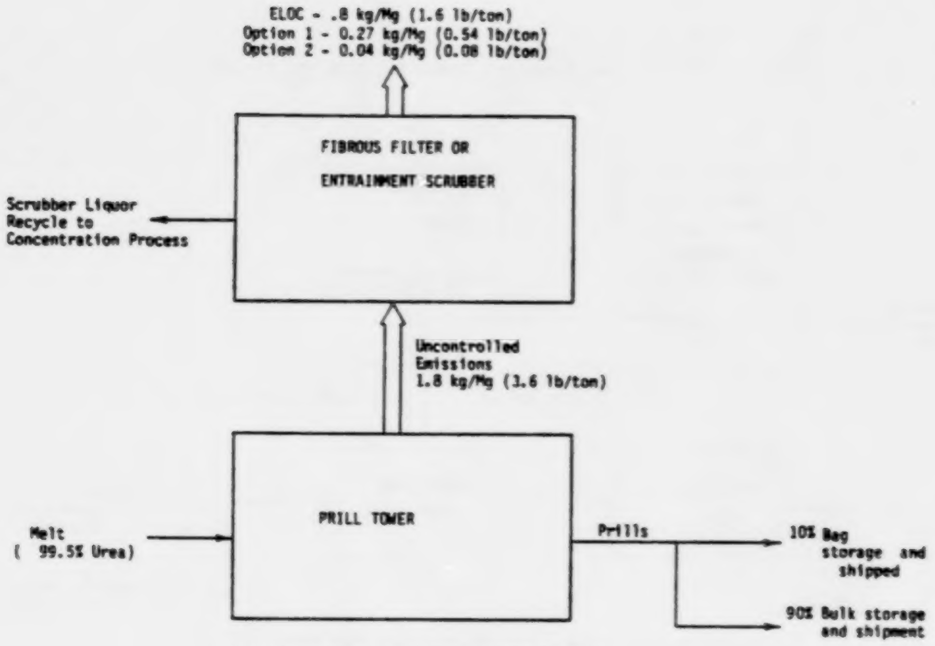

ELOC - 0.8 kg/Mg (1.6 lb/ton)
Option 1 - 0.28 kg/Mg (0.57 lb/ton)
Option 2 - 0.04 kg/Mg (0.08 lb/ton)
ELOC - 0.1 kg/Mg (0.2 lb/ton)
FIBROUS FILTER OR ENTRAINMENT SCRUBBER
TRAY TYPE SCRUBBER
Recycle to Concentration Process
Scrubber Liquor
Uncontrolled Emissions 1.9 kg/Mg (3.8 lg/ton)
Uncontrolled Emissions 3.9 kg/Mg (7.8 lb/ton)
Melt (99.5% Urea)
NFB PRILL TOWER
Prills
ROTARY DRUM COOLER
Prills
10% Bag storage and shipment
90% Bulk storage and shipment

(a) Nonfluidized bed prill tower, agricultural grade Model Plants 1-3

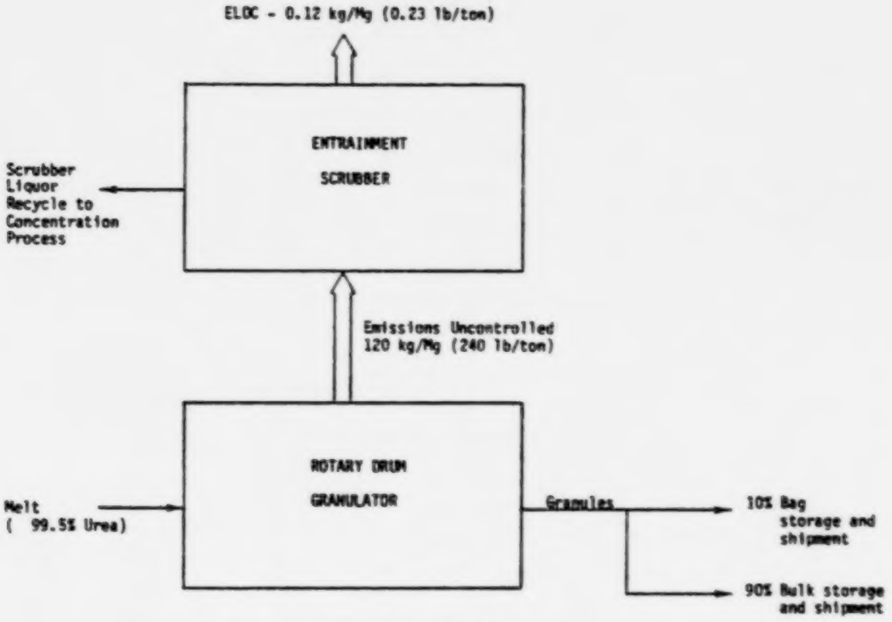

ELOC - 0.6 kg/Mg (1.2 lb/ton)
Option 1 - 0.47 kg/Mg (0.93 lb/ton)
Option 2 - 0.06 kg/Mg (0.12 lb/ton)
FIBROUS FILTER OR ENTRAINMENT SCRUBBER
Scrubber Liquor Recycle to Concentration Process
Uncontrolled Emissions 3.1 kg/Mg (6.2 lb/ton)
Melt (99.5% Urea)
FB PRILL TOWER
Prills
10% Bag storage and shipment
90% Bulk storage and shipment

(b) Fluidized bed prill tower, agricultural grade, Model Plants 4-6.

Figure 5-1. Process diagrams for Model Plants 1-6.



(a) Prill tower, feed grade, Model Plant 7



(b) Granulator, Model Plants 8 - 10

Figure 5-2. Process diagrams for Model Plants 7-10.

currently in operation in the United States and further expansion of granulator production is expected to be met through the use of drum granulators. Therefore, model plants were chosen to represent three types of solid production techniques: nonfluidized bed prilling, fluidized bed prilling, and drum granulation.

Model Plants 1 through 7 represent prilling plants utilizing a single prill tower. Model Plants 1 through 3 and 7 utilize nonfluidized bed prill towers and Model Plants 4 through 6 use fluidized bed prill towers. For the nonfluidized bed prilling plants, supplementary cooling of the prills is assumed to be provided by a rotary drum cooler although some plants currently operating do not use a supplementary cooling device.

Except for Model Plant 7, all model prilling plants produce agricultural grade product. These plants may also produce feed grade product through a change in melt distributor and a reduction in air flow rates. However, feed grade towers are assumed to have lower emissions. For the purpose of presenting conservative economic and environmental impact analyses in subsequent chapters, it is assumed that Model Plants 1 through 6 produce agricultural products exclusively.

Model Plant 7 represents a prilling facility dedicated to feed grade production only. This plant was selected to account for the possibility of granulators continuing to displace prill towers for agricultural grade production, and the subsequent need for prill towers to produce feed grade solids exclusively. This possibility could arise because, at the present time, feed grade solids are not produced by granulation.

Model Plants 8 through 10 use rotary drum granulators for solids formation. In contrast to prilling plants which use a single prill tower of varying capacity, granulator plants generally use multiple granulator trains of a single uniform capacity to achieve total plant production.

5.1.2 Plant Capacities

Currently, prilling plants producing agricultural grade urea range in capacity from 167 Mg/day (186 tons/day) to 1150 Mg/day (1270 tons/day).

Using this range as a guide, a small model prilling plant of 182 Mg/day (200 tons/day) capacity and a large model prilling plant of 1090 Mg/day (1200 tons/day) capacity were selected. Because this size range is considerable, an intermediate size model prilling plant of 726 Mg/day (800 tons/day) was selected. The choice of an intermediate size nearer the larger plant size reflects the tendency for facilities to be large in order to take advantage of economies of scale.

Only one size of model feed grade prilling plant was selected. The two plants currently producing feed grade exclusively are small. Both produce less than 217 Mg/day (240 tons/day). Therefore, a single small feed grade model plant of 182 Mg/day (200 tons/day) capacity was selected.

Granulator plant sizes vary according to the number of granulators operated at any particular plant location. The number of granulators currently operated at one location varies between one and seven. However, many of these plants brought granulators on line in increments. Model Plants 8 through 10 utilize one, two and three 363 Mg/day (400 tons/day) capacity granulator trains respectively to represent a range of existing plant capacities.

5.1.3 Operating Hours

Urea plants usually operate continuously except for scheduled maintenance shutdowns and unscheduled equipment failures. Total shutdown time is estimated at nine weeks per year. Thus, each model plant operates 43 weeks/year, 7 days/week, and 24 hours/day for a total production time of 7224 hours/year.

5.1.4 Raw Material and Utility Requirements

In each of the model plants, ammonia and carbon dioxide are processed to form an aqueous urea solution which is then concentrated to 99+ percent urea. This molten urea is mixed with about 0.4 weight percent formaldehyde additive and then solidified either by prilling or granulation. The purpose of the formaldehyde additive is to prevent caking and breakage of the solid product. Because the model plants use the same types of solution production and concentration equipment and produce similar products (99+ percent solid urea with 0.4 percent formaldehyde additive), they have the same basic raw material requirements per unit of urea product. Thus, the annual raw material requirements for the four sizes of model plants given in Table 5-2 are used for all model plants.

Also presented in the table are utility requirements for the various sizes of model plants. These requirements represent the total utility needs of the entire urea manufacturing plant, including solution synthesis and concentration processes. Electrical energy and steam requirements vary slightly between prilling plants and granulation plants. However, the difference is relatively small compared to the total plant energy usage. Therefore the utility requirements listed in Table 5-2 are used for all model plants.

5.2 DETERMINATION OF EXISTING CONTROL LEVELS

The Existing Level of Control (ELOC) is that level of control which is currently applied to emissions from solid urea producing processes in the urea industry. Table 5-3 summarizes the ELOC chosen for the emission sources in the urea industry. Consideration is first given to current state regulations which apply to the emission sources. State regulations usually define the primary constraint on emissions. However, for many emission sources, a sizeable discrepency exists between actual emission levels and those levels allowed by state regulations.

Several factors are responsible for the disparity between the allowable state emission levels and measured industry emissions. First, the test method used by state and industry personnel varies from state to state and may be considerably different from the method used in this study. The sampling procedures which have been endorsed and used by the States include EPA's Method 5, the American Society of Mechanical Engineers' Performance Test Code (PTC) 27, and modifications of these procedures. The collection efficiencies of the various sampling procedures depend upon such factors as the type of filter used, the temperature of the filter, whether condensible emissions are included, and the sample recovery and analytical procedures. Even when two state emission standards are identical, one standard can effectively be more stringent when the sampling procedure specified collects a higher percentage of emissions.

TABLE 5-2. RAW MATERIAL AND UTILITY REQUIREMENTS FOR MODEL PLANTS[1-3]

Plant Size Mg/day (tons/day)	Annual Production Mg/yr (tons/yr)	Ammonia Consumption Mg/yr (tons/yr)	Carbon Dioxide Consumption Mg/yr (tons/yr)	Formaldehyde Consumption Mg/yr (tons/yr)	Steam Use Mg/yr (tons/yr)	Electricity Use TJ/yr (Mw-hr/yr)	Cooling Water Use[a] $m^3 x 10^6$/yr (gal $x 10^6$/yr)	Cooling Water Use[b] m^3/yr (gal $x 10^6$/yr)
182 (200)	54,700 (60,200)	31,700 (34,900)	41,300 (45,500)	219 (241)	79,300 (87,300)	23.9 (6,620)	3.98 (1,050)	4090 (1.08)
363 (400)	109,000 (120,000)	63,200 (69,600)	82,300 (90,600)	436 (480)	158,000 (174,000)	47.7 (13,200)	7.91 (2,090)	8180 (2.16)
726 (800)	219,000 (241,000)	127,000 (140,000)	165,000 (182,000)	875 (964)	317,000 (349,000)	95.8 (26,500)	15.9 (4,190)	1640 (4,34)
1090 (1200)	328,000 (361,000)	190,000 (209,000)	248,000 (273,000)	1311 (1444)	475,000 (523,000)	134.4 (39,700)	23.8 (6,280)	24600 (6.50)

[a] Recirculated cooling water with 15°F rise across process

[b] Consumptive use of cooling water

TABLE 5-3. SUMMARY OF EXISTING EMISSION LEVELS

Emission Source	Uncontrolled Emissions kg/Mg (lb/ton)	Existing Controlled Emissions kg/Mg (lb/ton)	Control Equipment	Required Removal Efficiency
Prill Towers				
Agricultural Grade, Nonfluidized Bed	1.9 (3.8)	.80 (1.6)	Spray Tower Scrubber	57.9%
Agricultural Grade, Fluidized Bed	3.1 (6.2)	.60 (1.2)	Spray Tower Scrubber	80.6%
Feed Grade (either bed type)	1.8 (3.6)	.80 (1.6)	Spray Tower Scrubber	55.5%
Rotary Drum Granulators	103 (207)	.115 (.230)	Entrainment Scrubber	99.9%
Rotary Drum Coolers	3.9 (7.8)	.10 (.20)	Tray-Type Scrubber	97.4%

For example, a wet impinger collection device collects more particulate matter than a heated filter, which tends to vaporize some of the collected particles. Therefore, given equal emission standards, the standard requiring the wet impinger collector would be more stringent.

Secondly, sampling problems may compromise the state agency's ability to determine compliance. As an example, prill towers commonly exhaust through horizontal vents near the top of the prill tower. Because of the tower height, an outlet stack is not needed to gain acceptable dispersion of pollutants. Therefore, sampling locations are either very poor or nonexistant. Faced with sampling sites which will not yield accurate data, state officials find it difficult to use source tests as a compliance tool. Instead, opacity readings are often used as a measure of compliance.

Third, plants may find it to their advantage to control emissions to lower levels than are required by state regulations. Urea collected in scrubbers is recycled to the solution concentration process or to solution fertilizer make-up. This recovery of urea offsets much of the cost of control and may encourage a higher level of removal than is required by state regulations.

Finally, in some cases it has been reported that opacity standards are more difficult to meet than mass emission standards.[4] In these cases, industry may use a control device to meet opacity standards which also reduces mass emissions well below the state regulation for mass emissions.

A discussion of existing regulations is presented in Section 5.2.1. Existing levels of control are presented in the sections following for prill towers, rotary drum granulators, and rotary drum coolers. Where appropriate, the influence of the factors mentioned previously is addressed.

5.2.1 Existing Emissions Limitations

Standards limiting particulate emissions are in effect in all 50 states. The regulations are of three types: opacity limits, exhaust gas particulate concentration limits, and particulate emission limits calculated from process weights. The process weight regulations can take the form of an allowable emission factor expressed as kg (lb) of particulate allowed per Mg (ton) of production. This section focuses on the regulations in effect in 23 states in which urea plants are presently located. In nearly all of the states, industrial source emissions are limited by both opacity standards and process weight standards.

Table 5-4 presents a summary of opacity, concentration, and process weight standards in the 23 states.[5] In California, regulations differ by district. The regulation presented in Table 5-4 for California are those for the Los Angeles County Air Pollution Control District, which are the most stringent.

Twenty of the 23 states in which urea plants are located have standards limiting the opacity of an exhaust stream to 20 percent. This is the most stringent opacity regulation affecting urea plants and is also the typical regulation. A variation of the 20 percent opacity standard is a standard which allows a source to exceed 20 percent for a certain time period (for example, 6 minutes in any one hour). Two of 23 states in which urea plants are located have standards limiting opacity to 40 percent and one state has a standard of 30 percent.

Almost all states have particulate emission rate limits based on the amount of production. As shown in Table 5-4, particulate emissions from a 363 Mg/day (400 tons/day) process are limited to a range of 5.19 to 71.44 kg/hr (11.41 to 257.20 lb/hr), or 0.34 to 4.72 kg/Mg (0.69 to 9.43 lbs/ton). Illinois and the Los Angeles County Air Pollution Control District in California have the most stringent process weight regulation limiting a 363 Mg/day (400 tons/day) process to emissions of 5.19 and 5.97 kg/hr (11.41 and 13.14 lb/hr) respectively, or 0.34 to 0.40 kg/Mg (0.69 to 0.79 lbs/ton).

In addition to the process weight rate equation ranging from state to state, the method of enforcement also varies from state to state. Some states consider each process or stack as a source. Other states consider the allowable emission rate to apply to the combined emissions from all the processes or stacks at the entire plant or from one building

TABLE 5-4. EMISSIONS STANDARDS AFFECTING UREA PLANTS

State	Opacity (percent)	Grains/ft^3	Grams/m^3	Process weight regulation		Allowable Particulate Emissions in lb/hr for 400 ton/day^a process	Allowable Particulate Emissions in kg/hr for 363.6 Mg/day^a process
				$P < 30$ ton/hr	$P \geq 30$ ton/hr		
Alaska	20	0.05	0.11				
Alabama	20			$3.59(P)^{0.62}$	$17.31(P)^{0.16}$	20.54	9.43
Arkansas[b]	20			$0.058P^{0.803^4}$	$1.92P^{0.423^4}$	157.20	71.44
California[c]	20					13.14	5.97
Florida	20			$3.59(P)^{0.62}$	$17.31(P)^{0.16}$	20.54	9.34
Georgia	20			$3.59(P)^{0.62}$	$17.31(P)^{0.16}$	20.54	9.34
Idaho	20			$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
Illinois[d]	30			$2.54(P)^{0.534^c}$	$24.8(P)^{0.16^c}$	11.41	5.19
Iowa	40			$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
Kansas	20			$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
Louisiana	20	0.3	0.69	$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
Mississippi	40			$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
Missouri	20	0.3	0.69	$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
Nebraska	20			$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
New York[e]	20	0.05	0.11	$3.91(P)^{0.67}$	$39.(P)^{0.082}-50$	25.74	11.70
North Carolina	20			$9.377(P)^{0.3067}$		22.22	10.10
Ohio	20			$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
Oklahoma	20	0.3	0.69	$4.10(P)^{0.67}$	$(55.0(P)^{0.11})-40$	27.00	12.27
Oregon	20	0.1	0.23	$4.10(P)^{0.67}$	$(55.(P)^{0.11})-40$	27.00	12.27
Tennessee	20	0.25	0.58	$3.59(P)^{0.62}$	$17.31(P)^{0.16}$	20.54	9.34
Texas	20			$3.12(P)^{0.985}$	$25.4(P)^{0.287}$	49.85	22.65
Washington	20	0.1	0.23				
Wyoming	20			$3.59(P)^{0.62}$	$17.31(P)^{0.16}$	20.54	9.34

[a] Based on 24 hour operation.

[b] Process weight regulations for Arkansas apply to production rates of $100 \leq P \leq 10^4$ lb/hr and $10^4 \leq P \leq 10^6$ lb/hr, respectively.

[c] Based on Los Angeles county APCD process weight rate table.

[d] Process weight regulations for Illinois apply to production rates of $P \leq 450$ tons/hr and $P > 450$ tons/hr, respectively.

[e] Process weight regulations for New York apply to production rates of $P \leq 100{,}000$ lb/hr and $P > 100{,}000$ lb/hr, respectively.

at the plant. The most typical interpretation used is the first method which is also the less stringent of the two.

Because the state process weight equations are nonlinear with respect to production, the allowable emission factor (kg/Mg or lb/ton) changes with different plant sizes. Table 5-5 presents the allowable emissions for various sizes of plants by state, for the states with solid urea production capacity. Also included at the bottom of the table are the average emission limitations weighted by total solid production, prill production, and granule production respectively. If the state process weight regulations were the only factor affecting industry emissions, it would be expected that the existing level of control (ELOC) could be approximated by these weighted averages.

5.2.2 ELOC of Nonfluidized Bed Prill Towers Producing Agricultural Grade Prills

Industry data presented in Chapter 3 indicates varying uncontrolled emission rates of .39 - 1.79 kg/Mg (.78 - 3.58 lb/ton) for nonfluidized bed prill towers. Although much of this variability can be attributed to actual differences in uncontrolled emissions, the difficulties involved in obtaining accurate emission measurements of prill towers also play a role. These difficulties include:

- Low particle concentration
- Poor or nonexistant stack sampling locations
- Hygroscopic nature of urea particles
- Dissociation of urea particles at high temperatures encountered in collection filters

The variability in emissions, in conjunction with the variability in state regulations, results in differing levels of control in the industry. Seven of fifteen existing nonfluidized bed prill towers utilize control devices, while the rest are uncontrolled. A new prill tower may or may not require a control device to meet applicable state regulations depending on the particular situation.

For the purpose of this analysis, an emission level of 0.8 kg/Mg (1.6 lb/ton) was chosen to represent the ELOC for nonfluidized bed prill

TABLE 5-5. ALLOWABLE EMISSIONS BY PLANT SIZE (Metric Units)

	182 Mg/day		364 Mg/day		737 Mg/day		1091 Mg/day	
	kg/hr	kg/Mg	kg/hr	kg/Mg	kg/hr	kg/Mg	kg/hr	kg/Mg
Alabama	6.08	.803	9.34	.617	13.79	.455	14.71	.324
Alaska								
Arkansas *	53.32	7.036	71.5	4.717	95.8	3.162	113.7	2.502
California	4.95	.654	6.01	.397	7.06	.233	7.79	.172
Georgia	6.08	.802	9.34	.617	13.79	.455	14.71	.324
Iowa	7.71	1.019	12.27	.810	18.59	.614	20.3	.446
Kansas	▪	▪	▪	▪	▪	▪	▪	▪
Louisiana	▪	▪	▪	▪	▪	▪	▪	▪
Mississippi	▪	▪	▪	▪	▪	▪	▪	▪
Missouri	▪	▪	▪	▪	▪	▪	▪	▪
New York	7.36	.971	11.70	.772	18.61	.614	24.4	.538
Ohio	7.71	1.019	12.27	.810	18.59	.614	20.3	.446
Oregon	▪	▪	▪	▪	▪	▪	▪	
Tennessee	6.08	.802	9.34	.617	13.79	.455	14.71	.324
Texas	11.45	1.511	22.7	1.496	31.6	1.043	35.5	.781
Wyoming	6.08	.802	9.34	.617	13.79	.455	14.71	.324
Straight Average [a]	7.29	.96	11.90	.79	17.66	.59	19.57	.43
Weighted Average [b]	7.30	.97	11.52	.76	17.22	.57	18.80	.42
Weighted Average Prills only [c]	7.10	.94	11.16	.74	16.56	.55	18.10	.40
Weighted Average Granules only [d]	7.65	1.01	12.15	.80	18.38	.61	20.03	.44

* This state defines an emission source as all process emissions for the entire plant while other states define an emission source as a single stack or process. Therefore, Arkansas was not included in the straight or weighted averages.

a - Straight arithmetic average

b - Weighted average based on percentage of solids production in each state

c - Weighted average based on percentage of prill production in each state

d - Weighted average based on percentage of granule production in each state

TABLE 5-5. ALLOWABLE EMISSIONS BY PLANT SIZE (English Units)

	200 TPD		400 TPD		800 TPD		1200 TPD	
	lb/hr	lb/ton	lb/hr	lb/ton	lb/hr	lb/ton	lb/hr	lb/ton
Alabama	13.37	1.604	20.54	1.233	30.34	.910	32.37	.647
Alaska								
Arkansas	117.3	14.071	157.2	9.433	210.8	6.323	250.2	5.004
California	10.89	1.307	13.22	.793	15.53	0.466	13.13	0.343
Georgia	13.37	1.604	20.54	1.233	30.34	.910	32.37	.647
Iowa	16.97	2.037	27.00	1.620	40.89	1.227	44.58	.892
Kansas	"	"	"	"	"	"	"	"
Louisiana	"	"	"	"	"	"	"	"
Mississippi	"	"	"	"	"	"	"	"
Missouri	"	"	"	"	"	"	"	"
New York	16.18	1.941	25.74	1.544	40.95	1.223	53.73	1.075
Ohio	16.97	2.037	27.00	1.620	40.89	1.227	44.58	.892
Oregon	"	"	"	"	"	"	"	"
Tennessee	13.37	1.604	20.54	1.233	30.34	.910	32.37	.647
Texas	25.19	3.022	49.85	2.991	69.49	2.085	78.06	1.561
Wyoming	13.37	1.604	20.54	1.233	30.34	.910	32.37	.647
Straight Average[a]	16.04	1.92	26.17	1.57	38.86	1.17	43.05	.86
Weighted Average[b]	16.05	1.93	25.34	1.53	37.89	1.14	41.37	.83
Weighted Average[c] Prills Only	15.61	1.87	24.55	1.47	36.43	1.09	39.83	.80
Weighted Average[d] Granules Only	16.82	2.02	26.73	1.60	40.44	1.21	44.06	.88

*This state defines an emission source as all process emissions for the entire plant while other states define an emission source as a single stack or process. Therefore, Arkansas was not included in the straight or weighted averages.

a - Straight arithmetic average
b - Weighted average based on percentage of solids production in each state
c - Weighted average based on percentage of prill production in each state
d - Weighted average based on percentage of granule production in each state

towers producing agricultural grade prills. This is the average allowable mass emission rate, based upon state regulations for a 363 Mg/day (400 ton/day) plant. In addition, it is assumed that the uncontrolled emissions for a nonfluidized bed tower are 1.9 kg/Mg (3.8 lb/ton) based upon EPA testing.

5.2.3 ELOC for Fluidized Bed Prill Towers Producing Agricultural Grade Prills

Uncontrolled emissions for fluidized bed towers are higher than uncontrolled emissions from nonfluidized bed towers. EPA tests of a fluidized bed tower show that uncontrolled emissions are 3.1 kg/Mg (6.2 lb/ton) for a plant producing agricultural grade prills. Industry data for controlled emissions from fluidized bed towers vary from 0.38 - 0.43 kg/Mg (0.76 - 0.86 lb/ton). EPA test data show controlled emissions of 0.39 kg/Mg (0.79 lb/ton) for a fluidized bed tower producing agricultural grade urea prills. All three fluidized bed towers are currently controlled to levels required by state regulations.

Based on this data, state regulations are being met by existing facilities and an average state regulation was used to establish the ELOC. For agricultural grade production, 0.6 kg/Mg (1.2 lb/ton) represents the allowable emission under an average state regulation for a typical size of fluidized bed prill tower (737 Mg/day or 800 ton/day).

5.2.4 ELOC for Feed Grade Prill Towers

During the production of feed grade urea, nonfluidized and fluidized bed towers operate with approximately the same air flow and have comparable uncontrolled emissions. The limited industry data reports that uncontrolled emissions for nonfluidized bed prill towers producing feed grade product range from 1.61 - 1.76 kg/Mg (3.22 - 3.51 lb/ton). EPA data for a feed grade fluidized bed prill tower show uncontrolled emissions of 1.68 kg/Mg (3.36 lb/ton). Based on these emissions any new feed grade prill towers would have to control emissions to meet state regulations. A 0.8 kg/Mg (1.6 lb/ton) of product emission level was chosen as the ELOC for prill towers producing feed grade based upon the average state regulations for 363 Mg/day (400 ton/day) plants. This is the same level selected for nonfluidized bed prill towers producing agricultural grade urea prills. The larger plant size used for establishing the fluidized bed, agricultural grade ELOC is not used since plants producing feed grade tend to be smaller.

5.2.5 ELOC for Granulators

All 19 existing granulators are controlled, 18 with entrainment scrubbers and one with a packed bed scrubber. A comparison of uncontrolled emissions and applicable state regulations indicates that collection efficiencies of better than 99 percent are required. In addition, since uncontrolled emissions are high, process economics dictate control at the source.

An emission level of 0.115 kg/Mg (0.230 lb/ton) of product was chosen as the ELOC for granulators. This level represents the emissions measured during EPA testing and is typical of existing industry practice.

5.2.6 ELOC for Rotary Drum Coolers

Solids cooling is required, in some cases, during the production of agricultural grade prills in a nonfluidized bed prill tower. Rotary drum coolers are used when sufficient cooling is not available in the prill tower.

Very little data is available to quantify typical uncontrolled emissions from coolers. One EPA test measured uncontrolled emissions of 3.9 kg/Mg (7.8 lb/ton). Industry data indicates four coolers have emission rates ranging from 0.01 to 0.1 kg/Mg (0.02 to 0.2 lb/ton). These levels are significantly below the allowable state regulations. No EPA data is available for controlled cooler emissions which would allow verification of the industry test data with an EPA approved method. However calculations based upon EPA particle size data in conjunction with manufacturers' control device performance specifications confirm that the devices in use are capable of reducing emissions to the levels reported by industry. Thus, an ELOC emission level of 0.1 kg/Mg (0.2 lb/ton) was selected. This level represents the highest controlled emissions reported by industry.

5.3 CONTROL OPTIONS

This section presents control devices recommended for application to control particulate emissions from urea solids producing and finishing processes. The selection of control devices (hereafter referred to as control options) to achieve various control levels is based on performance data from EPA testing and vendor information. Table 5-6 presents a summary of control options for each source. Subsections 5.3.1, 5.3.2, and 5.3.3 presents control options for prilling, granulation, and rotary drum cooling processes, respectively. Section 5.3.4 presents emission characteristics for each model plant.

5.3.1 Prill Towers

To control particulate emissions to the ELOC for prill towers, a spray tower scrubber is recommended. This scrubber exhibits a removal efficiency of from 56 to 82 percent depending on the type of tower. To reduce emissions to a lower level, an entrainment scrubber is recommended and designated as control option 1 for prill towers. The greatest degree of control is achieved by a wetted fibrous filter with a removal efficiency of 98 percent (control option 2 for prill towers).

5.3.2 Granulators

Particulate emissions from granulators are currently well controlled to prevent excessive product loss. Since granulators are currently achieving the ELOC with an entrainment scrubber, no other control options are recommended.

5.3.3 Rotary Drum Coolers

To meet the ELOC determined for rotary drum coolers, a plate impingement scrubber with a removal efficiency of 98 percent is recommended. Control options attaining greater levels of control are not defined.

5.3.4 Emissions Characteristics

Tables 5-7 through 5-16 define emission characteristics for each model plant. This data is presented in terms of emission sources and control options, as discussed in the previous sections.

TABLE 5-6. CONTROL EQUIPMENT PERFORMANCE PARAMETERS

Emission Source	Applicable Model Plants	Control Option	Control Device	Performance Parameters				
				Removal Efficiency	Pressure Drop		Liquid/Gas Ratio	
					kPa	(in. W.G.)	l/m^3	(gal/1000 ft^3)
Prill Tower	1-7	ELOC	Spray Tower	[a]	[a]	[a]	.40	3.0
	1-7	Option 1	Entrainment Scrubber	85%	1.3	5.0	.87	6.5
	1-7	Option 2	Wetted Fibrous Filter	98%	3.1	12.0	.27	2.0
Granulator	8-10	ELOC	Entrainment Scrubber	99.9%	4.1	16.0	.87	6.5
Cooler	1-3	ELOC	Plate Impingement (Tray Type) Scrubber	98%	1.3	5.0	.40	3.0

[a] Removal efficiency and pressure drop varies according to the specific Model Plant. Efficiencies range from 56 to 82 percent.

ELOC- Existing level of control.

TABLE 5-7. EMISSION CHARACTERISTICS FOR MODEL PLANT 1 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Prill Tower	ELOC	2690 (95000)	294 (70)	.0375 .0164	2.5	0.80 (1.60)
	Option 1	2690 (95000)	294 (70)	.0133 (.0058)	2.5	.285 (.570)
	Option 2	2690 (95000)	294 (70)	.0018 (.0078)	2.5	.038 (.076)
Cooler	ELOC	214 (7570)	305 (90)	.0586 (.0256)	4.5	.10 (.20)

TABLE 5-8. EMISSION CHARACTERISTICS FOR MODEL PLANT 2 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Prill Tower	ELOC	6850 (242,000)	294 (70)	0.0587 (0.0257)	2.5	0.80 1.60
	Option 1	6850 (242,000)	294 (70)	.0210 (.0092)	2.5	.285 (.570)
	Option 1	6850 (242,000)	294 (70)	.0028 (.0012)	2.5	.038 (.076)
Cooler	ELOC	858 (30280)	305 (90)	.0586 (.0256)	4.5	.10 (.20)

TABLE 5-9. EMISSION CHARACTERISTICS FOR MODEL PLANT 3 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Prill Tower	ELOC	9360 (340,000)	294 (70)	.0629 (.0275)	2.5	0.80 (1.60)
	Option 1	9360 (340,000)	294 (70)	.0224 (.0098)	2.5	.285 (.570)
	Option 2	9360 (340,000)	294 (70)	.0030 (.0013)	2.5	.038 (.076)
Cooler	ELOC	1290 (45,400)	305 (90)	.0586 (.0256)	4.5	.10 (.20)

TABLE 5-10. EMISSION CHARACTERISTICS FOR MODEL PLANT 4 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (°F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Prill Tower	ELOC	2830 (100,000)	294 (70)	.0268 (.0117)	2.5	0.60 (1.20)
	Option 1	2830 (100,000)	294 (70)	.0207 (.00904)	2.5	.465 (.930)
	Option 2	2830 (100,000)	294 (70)	.00277 (.00121)	2.5	.0620 (.124)

TABLE 5-11. EMISSION CHARACTERISTICS FOR MODEL PLANT 5 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (°F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Prill Tower	ELOC	8890 (314,000)	294 (70)	.0340 (.0148)	2.5	0.60 (1.20)
	Option 1	8890 (314,000)	294 (70)	.0263 (.0115)	2.5	.465 (.930)
	Option 2	8890 (314,000)	294 (70)	.00353 (.00154)	2.5	.0620 (.124)

TABLE 5-12. EMISSION CHARACTERISTICS FOR MODEL PLANT 6 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (°F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Prill Tower	ELOC	12,900 (457,000)	294 (70)	.0351 (.0153)	2.5	0.60 (1.20)
	Option 1	12,900 (457,000)	294 (70)	.0273 (.0119)	2.5	.465 (.930)
	Option 2	12,900 (457,000)	294 (70)	.00362 (.00158)	2.5	.0620 (.124)

TABLE 5-13. EMISSION CHARACTERISTICS FOR MODEL PLANT 7 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (°F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Prill Tower	ELOC	1080 (38,000)	311 (100)	.113 (.0491)	5.0	0.80 (1.60)
	Option 1	1080 (38,000)	311 (100)	.316 (.0138)	5.0	.270 (.540)
	Option 2	1080 (38,000)	311 (100)	.00421 (.00184)	5.0	.0360 (.0720)

TABLE 5-14. EMISSION CHARACTERISTICS FOR MODEL PLANT 8 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (°F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Granulator	ELOC	1360 (48000)	311 (100)	.0213 (.00932)	5.0	.115 (.230)

TABLE 5-15. EMISSION CHARACTERISTICS FOR MODEL PLANT 9 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (°F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Granulator	ELOC	2720 (96,000)	311 (100)	.0213 (.00932)	5.0	.115 (.230)

TABLE 5-16. EMISSION CHARACTERISTICS FOR MODEL PLANT 10 CONTROL OPTIONS

Emission Source	Control Level	Total Stack Flowrate dsm^3/min (dscfm)	Exhaust Temperature K (°F)	Particulate Concentration g/m^3 (gr/dscf)	Moisture Content %	Emission Factor kg/Mg (lb/ton)
Granulator	ELOC	4080 (144,000)	311 (100)	.0213 (.00932)	5.0	.115 (.230)

5.4 CONTROL ALTERNATIVES

5.4.1 Approach

Control alternatives for each model plant are summarized in Table 5-17. Each alternative is comprised of various control options (control devices) applied to each emission source in each model plant. In selecting the control options, three basic levels of emission control are considered for each emission source.

1. ELOC - Controlling emissions to the ELOC as defined in Section 5.2. This level of control would typically be required under existing state regulations.
2. Controlling emissions to achieve the greatest degree of reduction.
3. Controlling emissions to an intermediate level. This is between the ELOC and the greatest degree of emission reduction.

Selection of the intermediate and greatest levels of control is made on the basis of performance data in Chapter 4. For sources other than prill towers, the selection of control levels is limited to existing levels of control. Control alternatives will be referred to in subsequent chapters to facilitate economic and environmental impact comparisons.

TABLE 5-17. CONTROL ALTERNATIVES

Model Plant No.	Plant Configuration	Emission Sources	Control Alternatives		
			1	2	3
1-3	Nonfluidized bed, Agricultural grade production	Prill Tower	0	+	++
		Cooler	0	0	0
4-6	Fluidized bed, Agricultural grade production	Prill Tower	0	+	++
7	Nonfluidized bed, Feed grade production	Prill Tower	0	+	++
8-10	Granulator	Granulator	0		

Legend:
0 - ELOC
+ - Option 1
++ - Option 2

5.3 REFERENCES

1. Shreve, R.N. and J.A. Brink. Chemical Process Industries, Fourth Edition. New York, McGraw-Hill Book Company, 1977. pp. 284-287.

2. Kirk-Othmer (ed.). Encyclopedia of Chemical Technology, Volume 21. John Wiley & Sons, Inc., 1970. pp. 37-56.

3. Chemical Engineering (ed.). Sources and Production Economics of Chemical Products, Second Edition. New York, McGraw-Hill Publishing Company, 1979. pp. 277-279.

4. Trip report. Bornstein, M.I., GCA Corporation, to Noble, E.A., EPA:ISB. August 2, 1978. p. 2. Report of visit to C & I Gridler Incorporated in Louisville, Kentucky.

5. Memo from Stelling, J., Radian Corporation, to file. July 6, 1980. Compilation of state regulations on particulate emissions from urea plants.

6.0 ENVIRONMENTAL IMPACTS

The purpose of this chapter is to present the environmental impacts of the control alternatives for particulate emissions from emission sources in the urea industry. The emission sources to be considered are prill towers, rotary drum coolers, and rotary drum granulators. The air quality, water pollution, solid waste, and energy impacts associated with the application of the control alternatives to the model plants are identified and discussed in Sections 6.1 to 6.4, respectively. Additional impacts are described in Section 6.5.

6.1 AIR POLLUTION IMPACT

The impact of each control alternative on air quality is evaluated in this section. Two impacts are considered: primary impacts, or the reduction of particulates due to the control equipment used, and secondary impacts; the pollutants generated as a result of applying the control equipment.

6.1.1 Primary Air Quality Impacts

The primary impact on air quality resulting from implementation of control alternatives is the reduction of particulate emissions into the atmosphere. Table 6-1 presents plant-wide (prill towers, granulators, coolers) emission and removal factors for the control alternatives and model plants presented in Chapter 5. Table 6-1 also presents the additional emissions reduction relative to the existing level of control (ELOC) for prill towers. The control alternatives for prill towers increase in their stringency from Alternative 1 (ELOC) to Alternative 3 (greatest degree of control). Using the emission reduction factors in Table 6-1, Table 6-2 presents the total anrual emissions reduction for Control Alternatives 2 and 3 over the ELOC.

TABLE 6-1. EMISSION AND REMOVAL FACTORS FOR CONTROL ALTERNATIVES

Model Plant		Emission Factors kg/Mg (lb/ton) Control Alternative			Absolute Reduction Over ELOC kg/Mg (lb/ton) Control Alternative		
Number	Plant Configuration	1	2	3	1	2	3
1-3	Nonfluidized bed Prill tower, cooler, Agricultural grade	0.900 (1.800)	0.385 (0.770)	0.138 (0.276)	0 (0) 0%	0.515 (1.030) 54%	0.762 (1.524) 84%
4-6	Fluidized bed Prill tower, Agricultural grade	0.600 (1.200)	0.470 (0.930)	0.062 (0.124)	0 (0) 0%	0.135 (0.270) 23%	0.538 (1.076) 90%
7	Prill Tower, Feed grade	0.800 (1.600)	0.270 (0.540)	0.036 (0.072)	0 (0) 0%	0.530 (1.060) 66%	0.764 (1.528) 96%
8-10	Granulator,	0.115 (0.230)					

TABLE 6-2. TOTAL ANNUAL REDUCTION OVER THE ELOC OF PARTICULATE EMISSIONS FOR CONTROL ALTERNATIVES,[a] Mg/year (Tons/year)

Model Plant Number	Plant Configuration	Plant Capacity Mg/day (Tons/day)	Control Alternatives 1	2	3
1	Nonfluidized bed tower, Agricultural grade	182 (200)	0 (0)	28.2 (31.0)	41.6 (45.8)
2	Nonfluidized bed tower, Agricultural grade	726 (800)	0 (0)	112.7 (124.0)	166.4 (183.0)
3	Nonfluidized bed tower, Agricultural grade	1090 (1200)	0 (0)	169.1 (186.0)	249.6 (274.5)
4	Fluidized bed tower, Agricultural grade	182 (200)	0 (0)	7.4 (8.1)	29.6 (32.5)
5	Fluidized bed tower, Agricultural grade	726 (800)	0 (0)	29.6 (32.5)	118.2 (130.0)
6	Fluidized bed tower, Agricultural grade	1090 (1200)	0 (0)	44.3 (48.8)	177.3 (195.0)
7	Feed Grade Tower	182 (200)	0 (0)	29.0 (31.9)	41.9 (46.1)
8	Granulator, Agricultural grade	363 (400)	0 (0)		
9	Granulator, Agricultural grade	726 (800)	0 (0)		
10	Granulator, Agricultural grade	1040 (1200)	0 (0)		

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[a] Based on an operating schedule of 301 days/year.

6.1.2 Secondary Air Quality Impacts

Secondary air pollutants are pollutants generated as a result of applying control equipment. There are no air pollutants generated directly by the control equipment required for each control level. However, the increased need for steam and electrical power to support the emission control systems will cause an increase in utility power plant emissions. Table 6-3 presents the emission reductions and corresponding increased power plant emissions for model urea plants and associated control alternatives. Also presented (as a percentage) is the increased power plant emission compared to the corresponding amount of urea plant-wide emission reduction. Increased power plant emissions range from 1 to 3 percent of the amount of plant-wide emission reductions.

6.1.3 Summary of Air Quality Impacts

The primary air pollutant emissions from affected facilities in the urea industry are particulates. The major benefit of implementing control alternatives is the reduction of these particulate emissions. A range of particulate reductions is possible, depending upon the control alternative chosen. Alternative 3 has the greatest particulate reduction for prilling operations. For Model Plant 3 (1090 Mg/day nonfluidized bed prill tower), the primary air quality impact would be an annual reduction of 249.6 Mg/year (274.5 ton/year) of particulate, with a corresponding secondary air quality impact due to increased power plant emissions of 5.0 Mg/year (5.5 ton/year) (2 percent of the plant-wide reduction). Hence, the net reduction in particulates from Model Plant 3 would be 244.5 Mg/year (269.0 ton/year), or 98 percent of the plant-wide reduction. Similarly, the impact of secondary pollutants would be small for the other model plants and their respective control alternatives relative to plant-wide particulate emission reductions.

6.2 WATER POLLUTION IMPACT

There would be no adverse water pollution impact due to the control alternatives, since the liquor used in the wet scrubbers controlling particulate emissions is typically recycled to the solution concentration

TABLE 6-3. SECONDARY AIR POLLUTION IMPACTS ASSOCIATED WITH THE APPLICATION OF CONTROL ALTERNATIVES TO TYPICAL UREA PLANTS

Plant Type	Emission Reduction over ELOC kg/Mg (lb/ton)			Power Plant Emission kg/Mg (lb/ton)			Impact Percent[c]		
	Control Alternative			Control Alternative			Control Alternative		
	1	2	3	1	2	3	1	2	3
Non Fluidized Bed Prill Tower, Agricultural grade	-	0.515 (1.030)	0.762 (1.524)	-[a]	0.0042[b] (0.0083)	0.0121[b] (0.0243)	-	1	2
Fluidized Bed Prill Tower, Agricultural Grade	-	0.135 (0.270)	0.538 (1.076)	-[a]	0.0044[b] (0.0089)	0.0140[b] (0.0279)	-	3	3
Prill Tower Feed Grade	-	0.530 (1.060)	0.764 (1.528)	-[a]	0.0028 (0.0056)	0.0076 (0.0151)	-	1	1

(a) There are no additional energy requirements attributable to control devices corresponding to the ELOC.

(b) These emissions are averages for the various plant capacities.

(c) Impact percent = $\left(\frac{\text{Power Plant Emission}}{\text{Emission Reduction Over ELOC}}\right) \times 100.$

concentration process or used for fertilizer solutions. The amount of excess water discharged, already present in urea plants since it is produced as a byproduct of the carbamate decomposition reaction, will be reduced because of the large amount of water entrained in the exhaust of a wet scrubber.

6.3 SOLID WASTE IMPACT

There would be no solid waste impact due to implementation of the control alternatives. Liquor from scrubbers is recycled to the solution concentration process or sold as fertilizer solution.

6.4 ENERGY IMPACT

Emission control equipment for the urea industry uses electricity and, indirectly, steam. The primary electrical demand is from the control equipment fans used in conjunction with normal operating equipment to generate sufficient airflow rates and pressure drops across the control equipment. Pumps which circulate the scrubber liquor also require electrical energy. Steam is used to concentrate the scrubber liquor to a level where it can either be recycled to the solution concentration process or sold as fertilizer solution.

Table 6-4 presents the total annual energy requirements of the control alternatives, assuming maximum steam requirements. The relative amounts of each type of energy (steam or electricity) vary by model plant. For prilling plants, 20-50 percent of the control equipment energy demand is represented by steam (assuming a scrubber liquor urea concentration of 20 percent by weight). Similarly, steam requirements can comprise more than 95 percent of the control equipment energy required for granulation plants. This high percentage is due primarily to the high uncontrolled emission rates from granulators which necessitate a greater scrubber liquor recycle rate.

Also presented in Table 6-4 are the incremental energy requirements over the ELOC. The greatest increase in energy consumption occurs for Control Alternative 3, Model Plant 6, a 1091 Mg/day (1200 ton/day) fluidized bed prill tower producing agricultural grade prills. The

TABLE 6-4. ANNUAL ENERGY REQUIREMENTS FOR UREA MODEL PLANT CONTROL ALTERNATIVES[1]

Model Plant	Control Alternative	10^9 Btu	TJ	Increase over Alternative 1 10^9 Btu	Increase over Alternative 1 TJ
1 Nonfluidized Bed Prill Tower, Agricultural Grade, 182 Mg/day (200 TPD)	1	10.4	11.0	-	-
	2	15.0	15.9	4.6	4.9
	3	24.3	25.6	4.6	4.9
2 Nonfluidized Bed Prill Tower, Agricultural Grade 728 Mg/day (800 TPD)	1	33.8	35.7	-	-
	2	46.3	48.9	12.5	13.2
	3	70.2	74.0	36.4	38.3
3 Nonfluidized Bed Prill Tower, Agricultural Grade, 1091 Mg/day (1200 TPD)	1	49.5	52.2	-	-
	2	67.2	70.9	17.7	18.7
	3	100.8	106.3	49.3	51.4
4 Fluidized Bed Prill Tower, Agricultural Grade, 182 Mg/day (200 TPD)	1	7.8	8.3	-	-
	2	12.3	12.9	4.5	4.6
	3	22.0	23.2	14.2	14.9
5 Fluidized Bed Prill Tower, Agricultural Grade, 728 Mg/day, (800 TPD)	1	26.5	28.0	-	-
	2	40.6	42.8	14.1	14.8
	3	71.5	75.4	45.0	47.4
6 Fluidized Bed Prill Tower, Agricultural Grade 1091 Mg/day (1200 TPD)	1	39.0	41.1	-	-
	2	59.5	62.8	20.6	21.7
	3	104.5	110.2	65.5	69.1
7 Prill Tower, Feed Grade 182 Mg/day (200 TPD)	1	3.3	3.5	-	-
	2	5.6	5.9	2.3	2.4
	3	9.8	10.4	6.5	6.9
8 Granulator 362 Mg/day (400 TPD)	1	275.9	291.0		
9 Granulator 728 Mg/day (800 TPD)	1	551.8	582.0		
10 Granulator 1091 Mg/day (1200 TPD)	1	828.8	873.3		

control equipment energy requirement increase over ELOC for this case is 69.1 TJ/year (65.5 x 10^9 Btu/year), or 63 percent. The total annual energy requirement of the control equipment for this plant is 110.2 TJ (104.5 x 10^9 Btu). The control equipment energy requirements of Model Plant 6 with Control Alternative 3 represent less than 7 percent of the total plant energy demand.

6.5 OTHER IMPACTS

There would be no significant noise impact due to implementation of any of the control alternatives in the urea industry. The increase in noise from properly designed control equipment would be insignificant compared to the noise associated with production process equipment.

6.6 REFERENCES

1. Memo from Stelling, J., Radian Corporation, to file. June 30, 1980. 22 p. Increased power plant emissions.

2. Memo from Stelling, J., Radian Corporation, to file. June 30, 1980. 5 p. Net consumption of water - test results and model plants.

7.0 COST ANALYSIS

A cost analysis of the control alternatives described in Chapter 5 is presented in this chapter. This chapter is divided into two major sections. Section 7.1 presents the costs associated with the various control alternatives, including an analysis of capital and annualized costs. Both new facilities and existing facilities are considered. Other costs that may result from the application of control equipment are considered in Section 7.2, including costs imposed by water pollution control regulations and solid waste disposal requirements.

7.1 COST ANALYSIS OF CONTROL ALTERNATIVES

7.1.1 Introduction

The costs of implementing control alternatives in the urea industry are presented in this section. The cost analysis is based upon the model urea plants and the control alternatives presented in Table 7-1 and discussed in Chapter 5. Three sources were considered in the model plant matrix. These were prill towers, rotary drum coolers, and granulators. Control options are identified for each source and were used as the basis for the formulation of the control alternatives.

The cost of purchasing, installing, and operating the various control devices are presented in the following sections. The purchased costs for the control equipment were obtained from vendor quotes.[1-4] Cost estimating manuals and published reports were used to determine costs for auxiliary equipment, (fans, pumps, motors, starters, downcomers, and stacks).[5-10] Equipment costs were scaled up to first quarter 1980 dollars (abbreviated 1Q80) using either the Marshall and Swift Equipment Cost Indices or Chemical Engineering Plant Cost Indicies.[10,11]

Total capital cost for installation of the various control devices was determined by applying component factors to the basic equipment

TABLE 7-1. SUMMARY OF UREA MODEL PLANTS AND CONTROL ALTERNATIVES

Model Plant No.	Size Mg/D (tons/D)	Configuration	Emission Sources	Control Alternatives		
				1	2	3
1	181(200)	Nonfluidized prill tower plant producing agricultural grade prills. Supplementary cooling required.	Prill Tower	0	+	++
2	726(800)		Cooler	0	0	0
3	1090(1200)					
4	181(200)	Fluidized bed prill tower plant producing agricultural grade prills. No supplementary cooling required.	Prill Tower	0	+	++
5	726(800)					
6	1090(1200)					
7	181(200)	Prill Tower Plant producing feed grade prills.	Prill Tower	0	+	++
8	363(400)	Granulation Plant	Granulator	0		
9	726(800)					
10	1091(1200)					

Legend:
0 - ELOC
+ - Option 1
++ - Option 2

costs. These component factors take into account direct costs (piping, electrical, instrumentation, structural costs, construction labor, etc.), indirect costs (engineering, contractor's fee, taxes, etc.), and contingencies. The capital component factors were obtained from a survey of industry and a cost estimating manual.[6,12]

The annual cost of operating and maintaining the control devices includes direct operating expenses (utilities, labor, maintenance) and capital charges. Capital charges include insurance, administrative overhead, taxes, and capital recovery (the annual cost for the payoff of the control devices).[13,14,15] Any credits or gains obtained from application of the control equipment is subtracted from the annual operating costs in order to obtain the net annual cost of the control alternatives. Credits are obtained from recovering urea captured by the control equipment.

Net annual costs are divided by the quantity of pollutant removed by the control equipment to determine the cost effectiveness of the control alternatives. Cost effectiveness is used as a means of comparing the various alternatives.

The costs associated with controlling emissions from new facilities are discussed in Section 7.1.2. Cost considerations for existing facilities are discussed in Section 7.1.3.

7.1.2 New Facilities

The capital and annualized costs of applying control alternatives to new urea solids production, finishing, and handling facilities are presented in this section. Costs associated with the control alternatives are presented in six subsections. Section 7.1.2.1 discusses important considerations used in the determination of control equipment costs. Section 7.1.2.2 presents the capital costs of the control alternatives, and Section 7.1.2.3 presents the annual cost of the control alternatives. The effect of the control alternatives on the cost of urea product is presented in Section 7.1.2.4. Section 7.1.2.5 compares the annual costs and cost effectiveness of the control options to Alternative 1 [existing level of control (ELOC)]. The base cost of a urea plant is discussed in Section 7.1.2.6.

7.1.2.1 Basis for Equipment Costs. This section presents important considerations in determining the costs of the control equipment. All the equipment, except for motors and starters, is made of stainless steel because of the corrosiveness of urea. Table 7-2 presents control equipment operating parameters which were obtained from vendors and are typical of industrial operation. The control devices and auxiliary equipment were sized to handle the airflows and emissions specified for the model plants in Tables 5-7 through 5-16. An example of the major equipment needed to control emissions from the sources in the model plants are presented in Tables 7-3a through 7-3c. For each emission source considered, the equipment for one plant size is presented as an example.

Due to differences in plant design, scrubbers selected for prill towers are of various sizes while only one scrubber size was selected for each granulator processing train. For prilling operations, the prill tower and finishing equipment are constructed and sized to handle whatever capacity was chosen for design production. Likewise, the scrubbers and auxiliary equipment used to control emissions from these facilities were sized to handle the entire airflow from the facility. The airflow through the solids production equipment varies with plant size, therefore, all of the control equipment had to be resized for each plant size. Granulation plants, on the other hand, employ processing trains of specific sizes, as discussed in Chapter 5. The model granulation plants chosen were 363 Mg/day (400 TPD), 726 Mg/day (800 TPD), and 1089 Mg/day (1200 TPD). A 363 Mg/day (400 TPD) granulator was used as a base, representing a single processing train. Control equipment was sized to handle the emissions from a single 363 Mg/day (400 TPD) plant. For 726 Mg/day (800 TPD) and 1089 Mg/day (1200 TPD) plants additional granulator processing trains were added, and the total equipment cost for controlling emissions was obtained by doubling or tripling the cost of controlling a single processing train.

TABLE 7-2. SPECIFICATIONS FOR PARTICULATE CONTROL SYSTEMS

I. Spray Tower (For prill towers)
    A. Pressure Drop: .77 kPa (3 in. W.G.)[a]
    B. Liquid to Gas Ratio: 0.40 ℓ/m^3 (3.0 gal/1000 acf)[a]
    C. Construction Material: 304 SS
    D. Fan Location: At scrubber inlet
    E. Scrubber Location: On top of prill tower

II. Entrainment Scrubber (For prill towers)
    A. Pressure Drop: 1.3 kPa (5 in. W.G.)
    B. Liquid to Gas Ratio: 0.87 ℓ/m^3 (6.5 gal/1000 acf)[a]
    C. Construction Material: 304 SS
    D. Fan Location: At Scrubber inlet
    E. Scrubber Location: At grade level

III. Wetted Fibrous Filter (For prill towers)
    A. Pressure Drop: 3.1 kPa (12 in W.G.)
    B. Liquid to Gas Ratio: 0.27 ℓ/m^3 (2 gal/1000 acf)[a,b]
    C. Construction Material: 304 SS
    D. Fan Location: At scrubber outlet
    E. Scrubber Location: At grade level

IV. Plate Impingement (Tray type) Scrubber (For coolers)
    A. Pressure Drop: 1.3 kPa (5 in. W.G.)
    B. Liquid to Gas Ratio: 0.40 ℓ/m^3 (3 gal/1000 acf)[a,c,d]
    C. Construction Material: 304 SS[b]
    D. Fan Location: At scrubber inlet

V. Entrainment Scrubber (For granulators)
    A. Pressure Drop: 4.1 kPa (16 in. W.G.)
    B. Liquid to Gas Ratio: 0.87 ℓ/m^3 (6.5 gal/1000 acf)a
    C. Construction Material: 304 SS
    D. Fan Location: At scrubber inlet

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a. Reference 12
b. Reference 5
c. Reference 2
d. Reference 3

TABLE 7-3a. EXAMPLE OF MAJOR EQUIPMENT REQUIREMENTS FOR CONTROL OF PRILL TOWERS (726 Mg/day (800 TPD). Fluidized bed/Agricultural grade configuration)

	Existing Level of Control
Control Device	Spray tower 304 SS, L/G = 3.0 gal/1000 ACF, Δp = 3"WG
Ducting	304 SS ductwork (4.0 feet diameter)
Fan (each)	60740 ACFM @ 111°F, 275 rpm, 50 hp.
Recirculation pump	1800 gpm, 30 ft TDH, 125 hp.
	Control Option 1
Control Device	Entrainment scrubber, 304 SS construction, L/G = 6.5 gal/1000 ACF, Δp = 5"WG
Ducting	304 SS ductwork (7.0 feet diameter), including ducting from top of prill tower to grade level.
Fan (each)	60740 ACFM @ 111 °F, 600 rpm, 125 hp.
Stack	7.0 feet diameter, 85 ft high, CS
Recirculation pump	2400 gpm, 100 ft TDH, 150 hp.
	Control Option 2
Control Device	Wetted Fibrous Filter, 304 SS construction, L/G = 2 gal/1000 ACF, Δp = 12"WG
Ducting	304 SS ductwork (10.5 feet diameter), including ducting from top of prill tower to grade level.
Fan	364,400 ACFM @ 111 °F, 1400 hp.
Stack	10.5 feet diameter, 120 ft high, CS
Recirculation pump	730 gpm, 100 ft TDH, 50 hp.
Preconditioning system	
Recirculation pump	550 gpm, 220 ft TDH, 75 hp.
Piping	CS and SS, as required

TABLE 7-3b. EXAMPLE OF MAJOR EQUIPMENT REQUIREMENT FOR CONTROL OF COOLERS
726 Mg/day (800 TPD)

	Existing Level of Control
Control Device	Plate Impingement (Tray Type) Scrubber, 304 SS construction, L/G = 3.0 gal/1000 ACF, Δp = 5" WG
Ducting	304 SS ductwork (3.0 feet diameter)
Fan	33800 ACFM @ 90°F, 1600 rpm, 200 hp
Stack	3.0 feet diameter, 40 ft high, CS
Recirculation pump	220 gpm, 100 ft TDH, 15 hp

TABLE 7-3c. EXAMPLE OF MAJOR EQUIPMENT REQUIREMENTS FOR CONTROL OF GRANULATORS
363 Mg/day (400 TPD)

	Existing Level of Control
Control device	Entrainment scrubber, 304 SS construction, L/G = 6.5 gal/1000 ACF, Δp - 16" WG
Ducting	304 SS ductwork, 5.0 feet diameter
Fan	64000 ACFM @ 190°F, 1250 rpm, 250 hp
Stack	5.0 feet diameter, 85 ft high, CS
Recirculation pump	400 gpm, 100 ft TDH, 15 hp

The cost of purchasing the control equipment is shown in Table 7-4. This table presents the cost of the control device and the cost for all the major equipment items associated with the control options. Table 7-5 presents an example cost breakdown of the major equipment items needed to control Model Plant 1 to the ELOC (Control Alternative 1). The same procedure shown in this example was used to derive the purchased equipment cost of the control alternatives for all model plants.

7.1.2.2 Capital Costs. Capital costs represent the total investment required for purchase and installation of the basic control equipment and associated auxiliaries. Capital cost estimates for each control system were developed with cost component factors.[6,12] These factors were applied to the control option costs presented in Table 7-6 to give installed capital costs. The capital costs for the control options were then combined to give the control alternative cost presented in Table 7-7. Costs for research and development and costs for possible production losses during equipment installation and start-up were not included. The costs are presented in first quarter 1980 dollars.

In computing the total installed cost of the wetted fibrous filter for Control Option 2 on prill towers, actual installation costs provided by the vendor were substituted for generalized installation costs in the component factor.[4] Therefore, the installation cost element of the component factor was deleted during these calculations.

7.1.2.3 Annualized Costs. Annualized costs represent the yearly cost of operating and maintaining the pollution control system. The basis of the annualized cost estimates are presented in Table 7-8. All annualized costs were based on 7224 hr/yr of operation.

Electricity costs were based on the power required to run the electric motors used to operate fans and pumps. Brake horsepower for the motors was determined by using power curves from cost estimating manuals.[6] The annual cost of electricity was based upon an electricity cost of $.04/kwh.

Annual labor cost for operation of the control equipment is the product of the total labor rate[15] ($17.45/hr), operating hours per

TABLE 7-4. PURCHASED EQUIPMENT COSTS ASSOCIATED WITH CONTROL OPTIONS (1Q80)

Model Plant	Control Option	Control Device Cost, 1000$			Total Control Equipment Cost, 1000$		
		Prill Tower	Cooler	Granulator	Prill Tower	Cooler	Granulator
1	ELOC[a]	203.4	11.6	-	334.0	33.2	-
	1	135.8	-	-	362.2	-	-
	2	468	-	-	622.2	-	-
2	ELOC	449.8	37.6	-	762.8	82.7	-
	1	372.3	-	-	864.3	-	-
	2	815	-	-	1140.0	-	-
3	ELOC	532.0	47.0	-	976.1	121.1	-
	1	467.7	-	-	1185.4	-	-
	2	1110	-	-	1507.6	-	-
4	ELOC	206.5	-	-	340.0	-	-
	1	140.0	-	-	368.1	-	-
	2	478	-	-	632.2	-	-
5	ELOC	506.6	-	-	903.6	-	-
	1	433.5	-	-	1092.1	-	-
	2	1025	-	-	1385.1	-	-
6	ELOC	749.5	-	-	1334.0	-	-
	1	620.5	-	-	1661.8	-	-
	2	1350	-	-	1995.9	-	-
7	ELOC	159.5	-	-	229.0	-	-
	1	62.2	-	-	182.0	-	-
	2	325	-	-	436.7	-	-
8	ELOC	-	-	69.4	-	-	180.5
9	ELOC	-	-	138.8	-	-	361.0
10	ELOC	-	-	208.2	-	-	541.5

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[a] ELOC = Existing level of control

TABLE 7-5. EXAMPLE OF PURCHASED EQUIPMENT COST BREAKDOWN OF MAJOR EQUIPMENT FOR ALTERNATIVE 1 ON A 181 Mg/day (200 TPD) NONFLUIDIZED BED PRILL TOWER, AGRICULTURAL GRADE (MODEL PLANT 1), $1000 (1Q80).

Item	Cooler	Prill Tower	Total
Control Device	11.6	203.4	215.0
Fans, Motors, Starters	6.3	73.4	79.7
Pumps, Motors, Starters	7.5	19.7	27.2
Ducting	2.9	30.5	33.4
Stack	1.4	7.0	8.4
Tank	3.5		3.5
	33.2	334.0	367.2

TABLE 7-6. COMPONENT CAPITAL COST FACTORS[6,12] FOR A WET SCRUBBER AS A FUNCTION OF EQUIPMENT COST, Q

Component	Direct costs	
	Material	Labor
Major Equipment	1.00 Q	0.09 Q
Ductwork	0.11 Q	0.09 Q
Instrumentation	0.08 Q	0.07 Q
Electrical	0.06 Q	0.12 Q
Foundations	0.03 Q	0.05 Q
Structural	0.06 Q	0.03 Q
Sitework	0.02 Q	0.02 Q
Painting	0.005 Q	0.02 Q
Piping	0.09 Q	0.08 Q
Total direct costs	1.40 Q	0.50 Q
	1.90 Q	

Component	Indirect costs	
	Measure of costs	Factor
Engineering	10 percent material and labor	0.19 Q
Contractor's fee	15 percent material and labor	0.29 Q
Shakedown	5 percent material and labor	0.10 Q
Spares	1 percent material	0.01 Q
Freight	3 percent material	0.04 Q
Taxes	3 percent material	0.04 Q
Total indirect costs		0.67 Q
Contingencies - 20 percent of direct and indirect costs		0.51 Q
Total capital costs		3.08 Q

TABLE 7-7. CAPITAL COSTS OF CONTROL ALTERNATIVES FOR MODEL PLANTS, $1000 (1Q80)

Case[a]	Model Plant	Control Alternative	Total Control Equipment Cost	Total Installed Cost	Difference in Total Installed Cost (Alternative - Existing Level)
1-1	1	1	367	1131	-
1-2		2	395	1218	87
1-3		3	655	1695	564
2-1	2	1	845	2604	-
2-2		2	947	2916	312
2-3		3	1222	3173	569
3-1	3	1	1097	3379	-
3-2		2	1306	4024	644
3-3		3	1628	4232	853
4-1	4	1	340	1047	-
4-2		2	368	1133	86
4-3		3	632	1618	571
5-1	5	1	903	2783	-
5-2		2	1092	3363	580
5-3		3	1385	3545	762
6-1	6	1	1334	4108	-
6-2		2	1661	5112	1003
6-3		3	1955	5007	898
7-1	7	1	229	705	-
7-2		2	182	562	(142)
7-3		3	436	1118	412
8-1	8	1	180	555	-
9-1	9	1	361	1112	-
10-1	10	1	541	1668	-

[a] First number is model plant number; second number is control alternative number.

Note: Values in parentheses represent net credits or gains.

TABLE 7-8. BASES FOR SCRUBBER ANNUALIZED COST ESTIMATES (1980)

Direct operating costs	
Utilities	
Water	Condensate from solution formation processes assumed available free of charge[a]
Electricity	$.04/kWh
Operating labor	
Direct wage rate	$7.66/hour
Fringe benefits	25 percent of direct rate
Supervision	15 percent of direct rate
Total	$10.72/hr
Operating hours	
Process equipment	7,224 hours/year
Scrubbers	7,224 hours/year
	Each unit requires one eighth of an operator[16]
Maintenance	5.5 percent of capital investment
Capital charges	
Capital recovery factor	0.1669[b]
Taxes and insurance	5.0 percent of capital investment
Administrative overhead	2.5 percent of capital investment
Recovery credit	$50 in solution[c]

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[a] This condensate would contribute to a plant's water pollution loading, if not used by scrubbers and mist eliminators. Since costs of treatment and disposal are avoided, the assumption that it is available free of charge is conservative.

[b] Includes wages plus 40 percent for labor-related administrative and overhead costs. Cost (4077) updated using Hourly Wage Index: 260.4: 212.8.

[c] Based on a 15-year equipment life[12] and a 10.0 percent interest rate.[10]

[d] Recovery credit is taken as cost of urea (f.o.b. plant, $120/ton), less the steam cost of removing the scrubber water (12 MMBTU/ton at $5.29/M lbs steam, $70/ton urea).[16]

[e] Reference 13.

[f] Reference 15.

[g] Reference 6.

year of the control process (7224 hr/yr), and number of operators required to run to control equipment (1/8 operator/unit). The annual labor cost to operate a single control device is estimated to be $15,760/yr.

A conservative net credit of $55 per Mg ($50/ton) of urea was calculated for urea recovered in wet scrubbers. This recovery credit included the cost of removing all water from a 20 percent by weight urea solution in a single stage evaporator.[16] The total credit allowed for each control option was dependent upon the uncontrolled emissions, control device efficiency, and the assumed hours of operation.

An example of an annualized cost breakdown for Control Alternative 2 on Model Plant 2 is given in Table 7-9. The procedure shown in this example was used to determine the net annualized costs presented in Table 7-10 for the control options considered in this study. These costs were combined to give the net annualized costs of the control alternatives, which are presented in Table 7-11.

7.1.2.4 Effect of Control Alternatives on Product Cost. The impact of applying control alternatives on the price of the product was also determined and is presented in Table 7-11. This cost impact indicates the additional or credit cost per unit of urea produced. It was calculated by dividing net annual cost of the control alternative by annual model plant production.

7.1.2.5 Cost Effectiveness. Cost effectiveness is used as a means of comparing control alternatives, and is defined as the total annualized cost of the pollution control system divided by the quantity of pollutant removed by the system. The cost effectiveness of the control alternatives can be compared directly to the ELOC by using the following equation.

$$\text{Cost Effectiveness} = \frac{C_x - C_E}{P_x - P_E}$$

C_x = Net annualized cost to remove a quantity of pollutant (P_x) by alternative x.

C_E = Net annualized cost to remove a quantity of pollutant (P_E) to meet a specified ELOC.

TABLE 7-9. COMPONENT ANNUALIZED COSTS FOR ALTERNATIVE 2 MODEL PLANT 4.

Prill Tower, Control Option 2

Component	Cost, $1000 per year (1980)
Direct Costs	
Operating labor and supervision	15.8
Maintenance labor and materials	62.4
Utilities	
Electricity	58.0
Total Direct Costs	136.2
Administrative overhead	28.3
Capital recovery charges	149.1
Taxes and insurance	56.7
Total Capital Charges and Overhead	234.1
Total Annualized Costs (without product recovery)	370.3
Credit for particulate recovery	7.9
Entrainment Scrubber	
Total Credit	
Net Annualized Costs	362

TABLE 7-10. NET ANNUALIZED COSTS FOR CONTROL OPTIONS, 1000$ (1Q80)

Model Plant	Control Option	Prill Tower	Cooler	Granulator
1	ELOC	312	34	
	1	358		
	2	529		
2	ELOC	697	51	
	1	834		
	2	1028		
3	ELOC	894	66	
	1	1141		
	2	1375		
4	ELOC	314		
	1	362		
	2	537		
5	ELOC	815		
	1	1045		
	2	1255		
6	ELOC	1194		
	1	1571		
	2	1780		
7	ELOC	211		
	1	183		
	2	345		
8	ELOC			(649)
9	ELOC			(1314)
10	ELOC			(1979)

Note: Values in parentheses represent net credits or gains.

TABLE 7-11. NET ANNUALIZED COST AND COST EFFECTIVENESS OF CONTROL ALTERNATIVES FOR MODEL UREA FACILITIES (1Q80) (METRIC UNITS)

Case	Model Plant	Control Alternative	Net Annual Cost 1000$	Cost Effectiveness per unit urea recovered $/Mg	Cost Effectiveness Relative to ELOC* $/Mg	Effect on cost[a] of product $/Mg	Effect on cost of product:[a] increase over ELOC $/Mg
1-1	1	1	347.6	1299	-	6.35	-
1-2		2	393.2	1355	2027	7.20	0.85
1-3		3	564.5	1859	6023	10.31	3.96
2-1	2	1	748.1	699	-	3.42	-
2-2		2	886.0	763	1514	4.06	0.64
2-3		3	1079.1	889	2296	4.93	1.51
3-1	3	1	961.0	599	-	2.93	-
3-2		2	1207.8	693	1810	3.68	0.75
3-3		3	1441.6	792	2226	4.39	1.46
4-1	4	1	362.4	2654	-	6.62	-
4-2		2	362.6	2520	28	6.64	0.02
4-3		3	543.0	3273	6144	9.92	3.30
5-1	5	1	815.9	1494	-	3.73	-
5-2		2	1046.8	1819	7880	4.79	1.06
5-3		3	1262.1	1902	3795	5.77	2.04
6-1	6	1	1194.1	1457	-	3.64	-
6-2		2	1573.3	1822	8619	4.81	1.17
6-3		3	1788.0	1796	3370	5.45	1.81
7-1	7	1	211.1	3866	-	3.06	-
7-2		2	184.0	2202	(937)	3.37	(.49)
7-3		3	352.0	3654	3376	6.43	2.57
8-1	8	1	(649.1)	(57.9)	-	(5.93)	-
9-1	9	1	(1314)	(57.9)	-	(6.00)	-
10-1	10	1	(1979)	(57.9)	-	(6.03)	-

*ELOC = Existing Level of Control

Note: Values in parentheses represent net gains or credits.

[a] Based on a product price of $132/Mg of urea product ($120/ton).

TABLE 7-11. NET ANNUALIZED COST AND COST EFFECTIVENESS OF CONTROL ALTERNATIVES FOR MODEL UREA FACILITIES (1Q80) (ENGLISH UNITS)

Case	Model Plant	Control Alternative	Net Annual Cost 1000$	Cost Effectiveness per unit urea recovered $/ton	Cost Effectiveness Relative to ELOC[a] $/ton	Effect on cost[b] of product $/ton	Effect on cost of product:[b] increase over ELOC[a] $/ton
1-1	1	1	347.6	1178	-	5.77	-
1-2		2	393.2	1229	1839	6.53	.76
1-3		3	564.5	1686	5464	9.38	3.61
2-1	2	1	748.1	634	-	3.11	-
2-2		2	886.0	692	1374	3.68	0.57
2-3		3	1079.1	806	2083	4.48	1.37
3-1	3	1	961.0	543	-	2.66	-
3-2		2	1207.8	629	1642	3.34	0.68
3-3		3	1441.6	718	2019	3.99	1.33
4-1	4	1	362.4	2408	-	6.02	-
4-2		2	362.6	2286	25	6.03	0.01
4-3		3	543.0	2969	5574	9.02	3.00
5-1	5	1	815.9	1355	-	3.39	-
5-2		2	1046.8	1650	7149	4.35	0.96
5-3		3	1262.1	1725	3443	5.24	1.85
6-1	6	1	1194.1	1322	-	3.31	-
6-2		2	1573.3	1653	7819	4.36	1.05
6-3		3	1788.0	1629	3057	4.95	1.64
7-1	7	1	211.1	3507	-	3.51	-
7-2		2	184.0	1998	(850)	3.06	(.45)
7-3		3	352.0	3315	3063	5.85	2.34
8-1	8	1	(649.1)	(52.2)	-	(5.39)	-
9-1	9	1	(1314)	(52.5)	-	(5.46)	-
10-1	10	1	(1979)	(52.8)	-	(5.48)	-

Note: Values in parentheses represent net gains or credits.

[a] ELOC = Existing Level of Control.

[b] Based on a product price of $132/Mg of urea product ($120/ton).

7.1.2.6 Base Cost of Urea Plants. Capital costs of control alternatives may be compared with the total capital costs of new urea manufacturing plants. Table 7-12 presents ranges of average capital costs for complete urea production plants, including solution synthesis, solution concentration, and solids formation processes. These values may be compared with the total capital costs and the capital cost relative to ELOC of each control alternative presented in Table 7-7. The capital cost relative to ELOC of control alternatives range from 3 to 7 percent of the total plant costs.

The cost of producing urea has been estimated at 128 $/Mg (116 $/ton) for small plants and 101 $/Mg (92 $/ton) for large plants.[17,18] The major cost component of urea is the cost of natural gas used in manufacturing the ammonia feed to the urea synthesis process.

7.1.3 Existing Facilities

The cost for installing a control system in an existing plant is generally greater than the cost of installing a control system in a new facility with the same exhaust gas parameters because special design modifications are often required.

Cost components that may increase because of space restrictions and plant configuration are contractor and engineering fees, additional ducting and structural reinforcement. These costs vary from place to place and job to job depending on the difficulty of the job, the risks involved, and current economic conditions.

Estimating this additional installation cost or retrofit penalty is difficult because of these plant-specific factors and additional engineering requirements. However, these additional costs are not expected to be large or to preclude the application of control equipment.

7.2 OTHER COST CONSIDERATIONS

7.2.1 Cost Imposed by Water Pollution Control Regulations

The costs of wastewater treatment at plants in the nitrogen fertilizer industry have been researched by previous investigators.[22,23] These costs are related to effluent limitations placed on the fertilizer industry and are not associated with air pollution control. Effluents

TABLE 7-12. CAPITAL COSTS OF UNCONTROLLED UREA PLANTS[7,18] (1Q80)

Plant Size Mg/yr (TPD)	Relevant Model Plant Number	Cost Range $ millions	Average Cost $ millions
181 (200)	1, 4, 7	7.2 - 9.2	8.2
363 (400)	8	11.7 - 17.2	14.4
726 (800)	2, 5, 9	19.2 - 27.4	23.3
1089 (1200)	3, 6, 10	25.8 - 33.2	29.5

from air pollution control equipment are recycled to the solution process for economic reasons. Therefore, no additional wastewater treatment costs are expected due to air pollution control equipment.

7.2.2 Costs Imposed by Solid Waste Disposal Requirements

Due to the high solubility of urea, any solid wastes can be dissolved and used as liquid fertilizer or recycled to the solution process to produce solid urea. Thus, no additional solid waste is anticipated due to air pollution control equipment.

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APPENDIX A - EMISSION SOURCE TEST DATA

A.1 PLANT DESCRIPTIONS AND TEST RESULTS

A.1.1 Introduction

Available EPA data on particulate emissions and visible emissions from five different urea plants are presented in this Appendix. Results of formaldehyde and ammonia emission measurements are also presented. The uncontrolled and controlled emissions data included in this Appendix are analyzed and discussed in Chapters 3 and 4 respectively.

The five plants where tests were performed are identified as Plants A, B, C, D, and E. The sources tested at each plant are presented in Tables A-1 and A-2.

Mass emission measurements were determined by methods designated by EPA to provide consistent data and are similar or identical to the modified Method 5 presented in Appendix B. Visible emission measurements were performed according to EPA Method 9 by a certified visible emission evaluator. Particle size distributions were determined using a cascade impaction collector. All standard units are for 293 K (68°F) and 29.92 in. Hg. of pressure.

A brief description of each facility is presented followed by results of the testing. References for EPA emission tests are presented in Section A.2.

TABLE A-1. SUMMARY OF MASS EMISSION TESTING

		PRILL TOWER				GRANULATOR		EMISSION SPECIES TESTED		
		FEED GRADE		AGRICULTURAL GRADE						
Plant	Type[a]	Scrubber Inlet	Scrubber Outlet	Scrubber Inlet	Scrubber Outlet	Scrubber Inlet	Scrubber Outlet	Urea Particulates	Ammonia	Formaldehyde
A						X	X	X	X	X
B						X	X	X	X	X
C[b]	NFB		X		X			X	X	
D	FB	X	X	X	X			X	X	X
E	NFB			X	X			X	X	

[a] NFB = non-fluidized bed
FB = Fluidized bed

[b] Mass emission testing was also performed on a rotary drum cooler scrubber inlet

TABLE A-2. SUMMARY OF VISIBLE EMISSIONS AND PARTICLE SIZE DISTRIBUTION TESTS

	VISIBLE EMISSIONS			PARTICLE SIZE DISTRIBUTIONS					
				Granulator Scrubber		Prill Tower Scrubber		Cooler Scrubber	
Plant	Granulator Scrubber Outlet	Prill tower Scrubber Outlet	Cooler Scrubber Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
A	X[b]			X	X				
B	X			X					
C		X	X			X		X	
D[a]		X				X	X		
E		X	X			X			

[a] Visible emissions were also determined for the outlet of a baghouse controlling bagging operations

[b] Visible emissions not tested during test on Unit "C"

4.1.2 Plant A[1,2]

Testing at Plant A was performed to gather urea particulate, ammonia, and formaldehyde emission data for the "A" and "C" granulators. Urea and ammonia emission measurements were also performed on the main vent for the urea solution synthesis and concentration process. The granulators operate on a 24 hr/day, 7 days/week basis at a production rate of approximately 363 Mg/day (400 tons/day) for each. Each granulator exhaust is ducted through a wet entrainment scrubber and fan before being discharged from a stack. The urea synthesis and concentration process operates on a continuous basis to provide urea solution for the entire urea plant. The exhaust from this process is vented from four locations which are combined and discharged through a common stack. Testing was performed at the outlet of this common stack.

Mass emission tests and particle size distributions were conducted on the gas entering and exiting the "A" granulator scrubber. Visible emissions were determined for the exhaust exiting the 26 meter (85 foot) vertical stack from the "A" granulator scrubber. Mass emission tests were also conducted on gases exiting the "C" granulator scrubber. Two different tests were performed to examine and evaluate factors affecting the accuracy of urea sampling and analytical techniques. Objectives of this study included establishment of a reference and analysis method quantification of possible sample degradation during storage (conversion of urea to other components) determination of the accuracy and consistency of analytical methods, and evaluation of the interferring effects of ammonia in the sample. This study concluded that urea particulate measurements for both granulator tests are representative of emissions.

The results reported for the urea and formaldehyde measurements were determined for the samples using the colorimetric method of analysis. Ammonia concentrations were determined by direct nesslerization, for granulator "A" and nesslerization with preliminary distillation for granulator "C". Outlet emission data for test run 9 on October 11, 1978 was discredited because a portion of the sample was lost.

TABLE A-3. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING THE "A" GRANULATOR SCRUBBER AT PLANT A (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		10-10-78	10-10-78	10-11-78	
Isokinetic (%)		97.2	96.6	99.0	97.2
Production Rate (Ton/day)		395	389	350	378
Ambient Temp. °F (Ave. Dry bulb)		b	b	b	b
Relative Humidity		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	48970	50020	50670	49890
(dscf/min)	outlet:	52020	53090	55420	53500
Temperature	inlet:	161	163	161	162
(F°)	outlet:	100	98	103	100
Moisture (% Vol.)	inlet:	1.6	2.1	2.8	2.2
	outlet:	4.3	4.1	3.4	3.9
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (in. W.G.)		17.9	16.3	14.6	16.3
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		9.4	9.5	9.3	9.4
Liquor Urea Conc.(lb/gal)	inlet:	0.180	0.323	0.412	0.305
	outlet:	4.220	8.440	4.857	5.749
Urea Emissions					
Particulate Conc.	inlet:	11.260	13.050	10.940	11.75
(gr/dscf)	outlet:	0.00566	0.0104	0.00834	0.00812
Emission Rate	inlet:	4726	5594	4753	5024
(lb/hr)	outlet:	2.523	4.723	3.953	3.733
Emission Factor	inlet:	286.1	347.2	325.7	319.7
(lb/ton)	outlet:	0.154	0.290	0.271	0.238
Collection Efficiency (%)		99.9	99.9	99.9	99.9
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0934	0.0942	0.0813	0.0846
(gr/dscf)	outlet:	0.194	0.361	0.282	0.273
Emission Rate	inlet:	39.19	38.77	35.28	37.75
(lb/hr)	outlet:	86.31	164.30	134.00	128.20
Emission Factor	inlet:	2.372	2.406	2.418	2.399
(lb/ton)	outlet	5.282	10.080	9.182	8.181
Collection Efficiency (%)		<0	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet	b	b	b	b
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency		b	b	b	b

b = not available

TABLE A-4. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING THE "A" GRANULATOR SCRUBBER AT PLANT A. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		10-10-78	10-10-78	10-11-78	
Isokinetic (%)		97.2	76.6	94.0	97.2
Production Rate (Mg/day)		359	353	318	343
Ambient Temp (K) (Dry Bulb)		b	b	b	b
Relative Humidity (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	1385	1416	1434	1411
(dsm^3/min)	outlet:	1472	1502	1568	1514
Temperature	inlet:	345	346	345	345
(K)	outlet:	310	308	312	310
Moisture (% Vol.)	inlet:	1.0	2.1	2.8	2.2
	outlet:	4.3	4.1	3.4	3.9
Control Device Characteristics					
Device Type		Entrainment Scrubber			
Pressure Drop (kPa)		4.475	4.025	3.650	4.075
Liquid/Gas Ratio (1/m^3)		b	b	b	b
Liquor pH (Ave.)		9.4	9.5	9.3	9.4
Liquor Urea Conc.(mg/ℓ)	inlet:	21680	38720	49360	36590
	outlet:	506200	1012000	550000	689402
Urea Emissions					
Particulate Conc.	inlet:	25.761	29.878	25.046	26.899
(g/dsm^3)	outlet:	0.0129	0.0230	0.0191	0.0185
Emission Rate	inlet:	35760	42327	35964	38015
(g/hr)	outlet:	19.091	35.737	29.911	28.246
Emission Factor	inlet:	143.05	173.60	162.85	159.85
(g/kg)	outlet:	0.077	0.145	0.136	0.119
Collection Efficiency (%)		99.9	99.9	99.9	99.9
Ammonia Emissions					
Ammonia Conc.	inlet:	0.213	0.2571	0.186	0.205
(g/dsm^3)	outlet:	0.444	0.826	0.646	0.625
Emission Rate	inlet:	296.54	293.36	266.95	285.64
(g/hr)	outlet:	653.08	1243.20	1013.93	970.04
Emission Factor	inlet:	1.186	1.203	1.204	1.199
(g/kg)	outlet:	2.641	5.040	4.591	4.041
Collection Efficiency (%)		<0	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
10^3 (g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

b = Not available

TABLE A-5. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES EXITING THE "A" GRANULATOR SCRUBBER AT PLANT A (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		10-11-78	10-11-78	10-11-78	
Isokinetic (%)		100.7	101.7	101.2	101.1
Production Rate (Tons/day)		347	400	418	405
Ambient Temp. (°F)(Ave. Dry bulb)		b	b	b	b
Relative Humidity		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	52410	50270	50550	51080
(dscf/min)	outlet:	55350	54380	53550	54430
Temperature	inlet:	157	162	168	162
(F°)	outlet:	99	102	105	102
Moisture (% Vol.)	inlet:	1.6	2.4	2.7	2.3
	outlet:	5.4	4.1	4.3	4.6
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (in. W.G.)		15.5	14.9	14.1	14.8
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (lb/gal)	inlet:	b	b	b	b
	outlet:	b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	11.01	10.740	10.10	10.620
(gr/dscf)	outlet:	b	0.0126	0.00342	0.00800
Emission Rate	inlet:	4946	4629	4376	4650
(lb/hr)	outlet:	b	5.860	1.571	3.720
Emission Factor	inlet:	299	278	250	276
(lb/ton)	outlet:	b	0.352	0.0904	0.221
Collection Efficiency (%)		b	99.9	100	99.9
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0936	0.0614	0.0645	0.0732
(gr/dscf)	outlet:	b	0.134	0.168	0.151
Emission Rate	inlet:	42.040	26.450	27.940	32.140
(lb/hr)	outlet:	b	62.480	77.020	69.75
Emission Factor	inlet:	2.541	1.589	1.601	1.910
(lb/ton)	outlet	b	3.750	4.429	4.090
Collection Efficiency (%)		b	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet	0.000325	0.0000808	0.000427	0.000278
(gr/dscf)	outlet:	b	0.000126	0.0000715	0.0000988
Emission Rate	inlet:	0.146	0.0350	0.185	0.122
(lb/hr)	outlet:	b	0.0588	0.0328	0.0458
Emission Factor	inlet:	0.00883	0.00209	0.0106	0.00717
(lb/ton)	outlet:	b	0.00353	0.00189	0.00271
Collection Efficiency		b	<0	82	

b = not available

TABLE A-6. SUMMARY OF UREA, FORMALDEHYDE, AND AMMONIA TESTS ON GASES ENTERING AND EXITING THE "A" GRANULATOR SCRUBBERS AT PLANT A. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		10-11-78	10-11-78	10-11-78	
Isokinetic (%)		100	101	101	101
Production Rate (Mg/day)		360	363	380	368
Ambient Temp (K) (Dry Bulb)		b	b	b	b
Relative Humidity		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	1484	1424	1432	1447
(dsm^3/min)	outlet:	1567	1540	1517	1541
Temperature	inlet:	342	345	349	345
(K)	outlet:	310	312	314	312
Moisture (% Vol.)	inlet:	1.6	2.4	2.7	2.3
	outlet:	5.4	4.1	4.3	4.6
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (kPa)		3.88	3.73	3.53	3.70
Liquid/Gas Ratio (1/m^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc.(Mg/ℓ)	inlet:	b	b	b	b
	outlet:	b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	25.189	24.572	23.107	24.297
(g/dsm^3)	outlet:	b	0.0288	0.00783	0.0183
Emission Rate	inlet:	37425	30026	33111	35185
(g/hr)	outlet:	b	44.34	11.08	28.15
Emission Factor	inlet:	149.5	139	125	138
(g/kg)	outlet:	b	0.176	0.0452	0.111
Collection Efficiency (%)		b	99.9	100	99.9
Ammonia Emissions					
Ammonia Conc.	inlet:	0.214	0.140	0.147	0.164
(g/dsm^3)	outlet:	b	0.306	0.384	0.345
Emission Rate	inlet:	318.10	200.14	211.41	243.19
(g/hr)	outlet:	b	472.76	582.78	527.78
Emission Factor	inlet:	1.271	0.795	0.801	0.955
(g/kg)	outlet:	b	1.875	2.215	2.045
Collection Efficiency (%)		b	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	0.000744	0.000185	0.000976	0.000631
(g/dsm^3)	outlet:	b	0.000288	0.000164	0.000226
Emission Rate	inlet:	1.105	0.265	1.399	0.923
(g/hr)	outlet:	b	0.445	0.248	0.347
Emission Factor	inlet:	0.00442	0.00105	0.0053	0.00355
10^3 (g/kg)	outlet:	b	0.00172	0.00095	0.00136
Collection Efficiency (%)		b	<0	82	

b = Not available

TABLE A-7. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES EXITING THE "C" GRANULATOR SCRUBBER AT PLANT A. (English Units)

Test No.		1	2	3
General Data				
Date		12-18-78	12-19-78	12-19-78
Isokinetic (%)		107.2	106.7	108.2
Production Rate (Tons/day)		371	370	370
Ambient Temp. (°F)		b	b	b
Ambient Moisture (%)		b	b	b
Exhaust Characteristics				
Flowrate	inlet:	b	b	b
(dscfm)	outlet:	55180	54220	51130
Temperature	inlet:	b	b	b
(F°)	outlet:	92	102	104
Moisture (% Vol.)	inlet:	b	b	b
	outlet:	6.0	3.8	5.1
Control Device Characteristics				
Device Type			Entrainment Scrubber	
Pressure Drop (in. W.G.)		b	b	b
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b
Liquor pH (Ave.)		b	b	b
Liquor Urea Conc. (%) (Ave.)		b	b	b
Urea Emissions				
Particulate Conc.	inlet:	b	b	b
(gr/dscf)	outlet:	0.0278	0.0431	0.170
Emission Rate	inlet:	b	b	b
(lb/hr)	outlet:	13.14	20.19	7.438
Emission Factor	inlet:	b	b	b
(lb/ton)	outlet:	0.850	1.339	0.493
Collection Efficiency (%)		b	b	b
Ammonia Emissions				
Ammonia Conc.	inlet:	b	b	b
(gr/dscf)	outlet:	0.186	0.145	0.279
Emission Rate	inlet:	b	b	b
(lb/hr)	outlet:	87.72	68.02	122.36
Emission Factor	inlet:	b	b	b
(lb/ton)	outlet	5.674	4.511	8.114
Collection Efficiency (%)		b	b	b
Formaldehyde Emissions				
Formaldehyde Con.	inlet	b	b	b
(gr/dscf)	outlet:	0.00172	0.00210	0.00156
Emission Rate	inlet:	b	b	b
(lb/hr)	outlet:	0.813	0.986	0.683
Emission Factor	inlet:	b	b	b
(lb/ton)	outlet:	0.0526	0.0654	0.0453
Collection Efficiency (%)		b	b	b

TABLE A-8. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES EXITING THE "C" GRANULATOR SCRUBBER AT PLANT A. (Metric Units)

Test No.		1	2	3
General Data				
Date		12-18-78	12-19-78	12-19-78
Isokinetic (%)		107.2	106.7	108.2
Production Rate (Mg/day)		336	336	336
Ambient Temp. (K)		b	b	b
Ambient Moisture (%)		b	b	b
Exhaust Characteristics				
Flowrate	inlet:	b	b	b
(dsm^3/min)	outlet:	1563	1550	1448
Temperature	inlet:	b	b	b
(K)	outlet:	308	312	313
Moisture (% Vol.)	inlet:	b	b	b
	outlet:	6.0	3.8	5.1
Control Device Characteristics				
Device Type			Entrainment Scrubber	
Pressure Drop (kPa)		b	b	b
Liquid/Gas Ratio (l/m^3)		b	b	b
Liquor pH (Ave.)		b	b	b
Liquor Urea Conc. (%) (Ave.)		b	b	b
Urea Emissions				
Particulate Conc.	inlet:	b	b	b
(g/dsm^3)	outlet:	0.0636	0.0985	0.0388
Emission Rate	inlet:	b	b	b
(g/hr)	outlet:	59580	91590	33740
Emission Factor	inlet:	b	b	b
(g/kg)	outlet:	0.425	0.669	0.247
Collection Efficiency (%)		b	b	b
Ammonia Emissions				
Ammonia Conc.	inlet:	b	b	b
(g/dsm^3)	outlet:	0.424	0.332	0.639
Emission Rate	inlet:	b	b	b
(g/hr)	outlet:	39790	30860	55500
Emission Factor	inlet:	b	b	b
(g/kg)	outlet	2.837	2.256	4.057
Collection Efficiency (%)		b	b	b
Formaldehyde Emissions				
Formaldehyde Con.	inlet	b	b	b
(g/dsm^3)	outlet:	0.00393	0.00481	0.00356
Emission Rate	inlet:	b	b	b
(g/hr)	outlet:	369	447	310
Emission Factor	inlet:	b	b	b
(g/kg)	outlet:	0.0132	0.0327	0.0226
Collection Efficiency		b	b	b

TABLE A-9. SUMMARY OF RESULTS OF UREA, AMMONIA AND FORMALDEHYDE TESTS ON THE GASES EXITING THE "C" GRANULATOR SCRUBBER AT PLANT A. (English Units)

Test No.		4	5	6	Ave.
General Data					
Date		12-19-78	12-19-78	12-19-78	
Isokinetic (%)		106.2	106.2	106.2	106.8
Production Rate (Tons/day)		370	370	370	370
Ambient Temp. °F		b	b	b	b
Ambient Moisture (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dscfm)	outlet:	52910	51730	53750	53237
Temperature	inlet:	b	b	b	b
(F °)	outlet:	103	105	104	102
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	4.9	3.1	3.8	4.5
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (in. W.G.)		b	b	b	b
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%) (Ave.)		b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	0.0239	0.0146	0.0230	0.0251
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	10.85	6.492	10.61	11.46
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	0.720	0.431	0.704	0.757
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	0.161	0.152	0.139	0.177
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	72.95	67.56	64.04	80.57
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet	4.84	44.80	4.25	5.322
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet	b	b	b	b
(gr/dscf)	outlet:	0.00197	0.000974	0.00144	0.00164
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	0.893	0.432	0.663	0.746
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	0.0592	0.0286	0.0439	0.0493
Collection Efficiency					

b = not available

TABLE A-10. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES EXITING THE "C" GRANULATOR SCRUBBER AT PLANT A. (Metric Units)

Test No.		4	5	6	Ave.
General Data					
Date		12-19-78	12-19-78	12-19-78	
Isokinetic (%)		106.2	106.2	106.1	106.8
Production Rate (Mg/day)		331	331	331	330
Ambient Temp (K)		b	b	b	b
Ambient Moisture (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dsm^3/min)	outlet:	1498	1465	1522	1508
Temperature	inlet:	b	b	b	b
(K)	outlet:	312	314	313	312
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	4.9	3.1	3.8	4.5
Control Device Characteristics					
Device Type		Entrainment Scrubber			
Pressure Drop (kPa)		b	b	b	b
Liquid/Gas Ratio (1/m^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%) (Ave.)		b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	0.0547	0.0335	0.0527	0.0575
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	4921	2945	4813	5198
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	0.360	0.215	0.352	0.378
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	0.368	0.349	0.318	0.404
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	33040	30640	24050	36550
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	2.419	2.240	2.124	2.661
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	0.00451	0.00223	0.00329	0.00374
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	405	196	301	338
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	0.0296	0.0143	0.0219	0.0247
Collection Efficiency (%)		b	b	b	b

b = Not available

TABLE A-11. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES EXITING THE SOLUTION SYNTHESIS TOWER VENT AT PLANT A. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		10-13-78	10-13-78	10-13-78	
Isokinetic (%)		b	b	b	b
Production Rate Tons/day		b	b	b	b
Ambient Temp.(°F)		b	b	b	b
Ambient Moisture (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dscfm)	outlet:	1248	1202	990.9	1147
Temperature	inlet:	b	b	b	b
(F°)	outlet:	175	185	185	182
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	87.97	88.37	90.56	88.97
Control Device Characteristics					
Device Type			None		
Pressure Drop (in. W.G.)		b	b	b	b
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%)(Ave.)		b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	0.0061	0.00126	0.0152	0.00752
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	0.065	0.13	0.13	0.11
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	117.2	137.5	131.7	128.8
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	1254	1418	1179	1284
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet	b	b	b	b
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet	b	b	b	b
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency		b	b	b	b

b = Not available

TABLE A-12. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES EXITING THE SOLUTION SYNTHESIS TOWER VENT AT PLANT A. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		10-13-78	10-13-78	10-13-78	
Isokinetic (%)		b	b	b	b
Production Rate (Mg/day)		b	b	b	b
Ambient Temp. (K)		b	b	b	b
Ambient Moisture (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dsm^3/min)	outlet:	35.32	34.02	28.04	32.46
Temperature	inlet:	b	b	b	b
(K)	outlet:	352	358	358	355
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	87.97	88.51	90.56	88.97
Control Device Characteristics					
Device Type			None		
Pressure Drop (kPa)		b	b	b	b
Liquid/Gas Ratio ($1/m^3$)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%) (Ave.)		b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	0.0139	0.00288	0.0348	0.0172
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	29.51	59.02	59.02	49.94
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	268.1	314.6	301.3	294.7
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	569316	643772	535266	582936
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet	b	b	b	b
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet	b	b	b	b
(g/dsm^3)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

b = Not available

TABLE A-13. SUMMARY OF INLET AND OUTLET PARTICLE SIZING TEST RESULTS ON "A" GRANULATOR SCRUBBER AT PLANT A

Sampling Location	Test Date	Test Time	Aerodynamic Size Range, µm	Mass in Size Range, %
Scrubber Inlet	10/12/78	0919-0929	>2.2	100
Scrubber Outlet	10/12/78	1109-1509	>3.7	98.7
			2.7-3.7	0.00
			1.7-2.7	0.14
			1.0-1.7	0.21
			0.56-1.0	0.39
			<0.56	0.39
Scrubber Outlet	10/12/78	1629-2029	>3.7	89.35
			2.7-3.7	0.00
			1.7-2.7	7.32
			1.0-1.7	1.31
			0.56-1.0	1.05
			<0.56	0.97
Scrubber Outlet	10/13/78	0855-1255	>3.8	65.34
			2.8-3.8	0.00
			1.7-2.8	4.54
			1.1-1.7	0.67
			0.56-1.1	23.89
			<0.56	5.56
Scrubber Inlet	10/13/78	1316-1317	>2.3	100
Scrubber Inlet	10/13/78	1508-1509	>2.4	100

TABLE A-14. SIX MINUTE ARITHMETIC AVERAGES OF OCTOBER 10, 1978 OPACITY READINGS ON "A" GRANULATOR SCRUBBER STACK AT UREA PLANT A

Test Date	Time	Average Opacity for 6 minutes
10-10-78	11:15 - 11:20	5
	11:21 - 11:26	5
	11:27 - 11:32	5
	11:33 - 11:38	5
	11:39 - 11:44	5
	11:45 - 11:50	5
	11:51 - 11:56	5

TABLE A-15. SIX MINUTE ARITHMETIC AVERAGES OF OPACITY READINGS ON "A" GRANULATOR SCRUBBER STACK AT UREA PLANT A

Test Date	Time	Avg. Opacity for 6 min.	Test Date	Time	Avg. Opacity for 6 min.
10-11-78	09:24-09:29	5	10-11-78	14:19-14:24	5
	09:30-09:35	5		14:25-14:30	5
	09:36-09:38*	5		14:31-14:36	4.5
	09:47-09:52	5		14:37-14:42	2.5
	09:53-09:58	5		14:43-14:48	3.2
	09:59-10:04	5		14:49-14:54	0.8
	10:05-10:10	5		14:55-15:00	0.9
	10:11-10:16	5		15:01-15:06	3.2
	10:17-10:22	5		15:07-15:12	4
	10:23-10:28	5		16:10-16:15	5
	10:29-10:34	3.3		16:16-16:21	4.6
	10:35-10:40	0		16:22-16:27	5
	10:41-10:44*	0		16:28-16:33	1.8
				16:34-16:39	3.7
	11:27-11:32	3.7		16:40-16:45	1.1
	11:33-11:38	3.9		16:46-16:51	.5
	11:39-11:44	2.9		16:52-16:57	.3
	11:45-11:50	4		16:58-17:03	0
	11:51-11:56	2.5		17:04-17:09	0
	11:57-12:02	3.3		17:10-17:15	0
	12:03-12:08	1.8		17:16-17:21	0
	12:09-12:14	3.4		17:22-17:27	0
	12:15-12:20	4.2		17:28-17:33	.6
	12:21-12:26	4.7		17:34-17:39	.5
	12:27-12:32	4.3		16:40-17:45	0
	12:33-12:38	4.8		17:46-17:51	.3
	12:39-12:43*	5		17:52-17:57	1.5
	13:43-13:48	5		17:58-18:03	.7
	13:49-13:54	5		18:04-18:09	.5
	13:55-14:00	4.2		18:10-18:15	1.3
	14:01-14:06	5		18:16-18:21	0.8
	14:07-14:12	3.9		18:22-18:25*	0.7
	14:13-14:18	4.5			

*Averaging time less than 6 minutes.

TABLE A-16. SIX MINUTE ARITHMETIC AVERAGES OF OPACITY READINGS ON "A" GRANULATOR SCRUBBER STACK AT UREA PLANT A

Test Date	Time	Average Opacity for 6 Minutes
10-12-78	14:45-14:50	1.9
	14:51-14:56	1.3
	14:57-15:02	0.6
	15:03-15:08	2
	15:09-15:14	0
	15:15-15:20	1.4
	15:21-15:26	0
	15:27-15:30*	1.4

*Averaging time less than 6 minutes.

A.1.3 Plant B[3]

Testing at Plant B was performed to gather urea particulate, ammonia, and formaldehyde emission data for the "B" granulator as well as urea and ammonia emission data from the urea solution synthesis and concentration process. The granulator operates on a 24 hrs/day, 7 day/week schedule. Exhaust from the granulator is ducted to a wet entrainment scrubber and then a fan prior to being discharged through a 24 meter (80 foot) vertical stack. Testing was performed on the gases entering the granulator scrubber. The urea synthesis and concentration process operates continuously to provide urea solution for the entire urea plant. The exhaust from this process is vented from four locations which are combined and discharged through a common stack. Testing was performed at the outlet of this common stack.

Particle size distributions were determined for the granulator exhaust entering the granulator scrubber. Visible emissions tests were conducted on the emissions exiting the vertical exhaust stack from the scrubber.

The urea concentration in the samples was determined by the Kjeldal method of analysis and is corrected for possible urea loss during analysis. Ammonia concentrations were determined by direct nesslerization and corrected for possible conversion of urea to ammonia. Formaldehyde data was determined by the chromotropic acid method of analysis.

The inlet percent moisture values reported for the stack gas were based on separate moisture test runs. Moisture contents is typically measured concurrently with each test run.

TABLE A-17. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING THE "B" GRANULATOR SCRUBBER AT PLANT B (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		01-17-79	01-17-79	01-18-79	
Isokinetic (%)		102	103	102	102
Production Rate (Tons/day)		a	a	a	a
Ambient Temp. °F (Ave. Dry bulb)		69	68	67	68
Relative Humidity (%)		76	82	84	80
Exhaust Characteristics					
Flow ate (dscfm)	inlet:	40180	41410	41760	41117
	outlet:	46260	45590	45760	45870
Temperature (F°)	inlet:	192	190	183	189
	outlet:	101	101	103	101
Moisture (% Vol.)	inlet:	2.257	2.253	2.257	2.256
	outlet:	5.522	5.733	5.608	5.621
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (in. W.G.)		20.9	20.5	20.6	20.7
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		8.6	8.7	8.7	8.7
Liquor Urea Conc.(lb/gal)	inlet:	.00000101	.000000739	.000000838	.00000086
	outlet:	.00458	.00466	.00478	.00468
Urea Emissions					
Particulate Conc. (gr/dscf)	inlet:	6.238	6.516	6.511	6.425
	outlet:	0.0113	0.0118	0.0101	0.110
Emission Rate (lb/hr)	inlet:	2147	2312	2330	2264
	outlet:	4.499	4.583	3.931	4.342
Emission Factor (lb/ton)	inlet:	119.3	128.5	134.0	127.2
	outlet:	0.248	0.255	0.226	0.244
Collection Efficiency (%)		99.8	99.8	99.8	99.8
Ammonia Emissions					
Ammonia Conc. (gr/dscf)	inlet:	0.0999	0.1029	0.1191	0.1073
	outlet:	0.0676	0.1041	0.0582	0.0766
Emission Rate (lb/hr)	inlet:	34.40	36.52	42.62	37.85
	outlet:	26.80	40.17	22.82	30.10
Emission Factor (lb/ton)	inlet:	1.90	2.03	2.45	2.13
	outlet	1.48	2.26	1.31	1.69
Collection Efficiency (%)		22.1	0	46.5	20.5
Formaldehyde Emissions					
Formaldehyde Con. (gr/dscf)	inlet	0.000604	0.000361	0.000715	0.000560
	outlet:	0.000379	0.000176	0.000195	0.000250
Emission Rate (lb/hr)	inlet:	0.2070	0.1280	0.2560	0.1972
	outlet:	0.1503	0.0687	0.0764	0.0982
Emission Factor (lb/ton)	inlet:	0.0115	.0071	0.0147	0.0111
	outlet:	0.0083	.0038	0.0044	0.0055
Collection Efficiency (%)		27.7	46.3	70.2	50.2

a = considered confidential by manufacturer
b = not available

TABLE A-18. SUMMARY OF RESULTS OF UREA AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING THE "B" GRANULATOR SCRUBBER AT PLANT B (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		01-17-79	01-17-79	01-18-79	
Isokinetic (%)		103	104	102	103
Production Rate (Mg/day)		a	a	a	a
Ambient Temp. (K)		294	293	293	293
Relative Humidity (%)		76	82	84	80
Exhaust Characteristics					
Flowrate	inlet:	1111	1147	1161	1138
(dsm^3/min)	outlet:	1238	1217	1222	1225
Temperature	inlet:	362	361	357	360
(K)	outlet:	312	312	313	312
Moisture (% Vol.)	inlet:	2.257	2.253	2.257	2.256
	outlet:	5.522	5.733	5.608	5.621
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (kPa)		10.45	10.25	10.30	20.35
Liquid/Gas Ratio (1/m^3)		b	b	b	b
Liquor pH (Ave.)		8.6	8.7	8.7	8.7
Liquor Urea Conc. Mg/ℓ	inlet:	122	89	101	104
	outlet:	552400	561900	576000	563400
Urea Emissions					
Particulate Conc.	inlet:	13.340	13.930	13.920	13.740
(g/dsm^3)	outlet:	0.0242	0.0252	0.0215	0.0236
Emission Rate	inlet:	910400	990230	987900	95980056
(g/hr)	outlet:	1907	4.90	1660	1841
Emission Factor	inlet:	59.65	64.25	27.0	63.60
(g/kg)	outlet:	0.116	0.119	0.105	0.114
Collection Efficiency (%)		99.8	99.8	97.8	99.8
Ammonia Emissions					
Ammonia Conc.	inlet:	0.229	0.235	0.272	0.246
(g/dsm^3)	outlet:	0.155	0.238	0.133	0.175
Emission Rate	inlet:	15600	16560	19330	17170
(g/hr)	outlet:	12160	18450	10350	13650
Emission Factor	inlet:	0.95	1.01	1.22	1.06
(g/kg)	outlet:	0.74	1.13	0.65	0.85
Collection Efficiency (%)		22.1	<0	46.5	20.5
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	0.00138	.000826	.00164	.00130
(g/dsm^3)	outlet:	0.00220	.000402	.00045	.000572
Emission Rate	inlet:	94.20	.000058	.0000116	.0000894
(g/hr)	outlet:	.000068	.0000311	.000035	.0000446
Emission Factor	inlet:	0.00575	0.00355	0.00735	0.00550
(g/kg)	outlet:	0.00410	0.00190	0.00220	0.00270
Collection Efficiency (%)		27.8	46.3	70.1	50.3

a = Considered confidential by manufacturer
b = Not available

TABLE A-19. SUMMARY OF RESULTS OF UREA, AND AMMONIA TESTS ON GASES EXITING THE SOLUTION SYNTHESIS TOWER VENT AT PLANT B. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		01-18-79	01-19-79	01-19-79	
Isokinetic (%)		84.2	66.5	77.9	76.2
Production Rate Tons/day		a	a	a	a
Ambient Temp. °F		b	b	b	b
Ambient Moisture (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dscfm)	outlet:	306	402	339	349
Temperature	inlet:	b	b	b	b
(F°)	outlet:	193	136	191	190
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	67	57.9	64.5	63.1
Control Device Characteristics					
Device Type			None		
Pressure Drop (in. W.G.)		b	b	b	b
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%) Ave.)		b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	0.614	0.615	0.593	0.619
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	1.62	2.12	1.72	1.82
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	0.0271	0.0377	0.0306	0.0317
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	115.2	141.3	174.5	143.5
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	302.0	486.5	506.8	431
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet	5.09	8.64	9.00	8.02
Collection Efficiency (%)					
Formaldehyde Emissions					
Formaldehyde Con.	inlet	b	b	b	b
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency		b	b	b	b

a = Considered confidential by manufacturer
b = Not available

TABLE A-20. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES EXITING THE SOLUTION SYNTHESIS TOWER VENT AT PLANT B. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		01-18-79	01-19-79	01-19-79	
Isokinetic (%)		84.2	66.5	77.9	76.2
Production Rate (Mg/day)		a	a	a	a
Ambient Temp.		b	b	b	b
Ambient Moisture (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dsm^3/min)	outlet:	8.660	11.377	9.594	9.877
Temperature	inlet:	b	b	b	b
(K)	outlet:	362	359	361	360
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	67	57.9	64.5	63.1
Control Device Characteristics					
Device Type			None		
Pressure Drop (kPa)		b	b	b	b
Liquid/Gas Ratio ($1/m^3$)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%) (Ave.)		b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	1.405	1.407	1.337	1.416
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	735.5	962.5	780.9	826.3
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	0.0136	0.0189	0.0153	0.0159
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	263.3	323.3	399.3	328.3
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	137108	220916	230087	195674
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet	2.545	4.320	4.500	4.010
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet	b	b	b	b
(g/dsm3)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

b = Not available

TABLE A-21. SUMMARY OF INLET PARTICLE SIZE TEST RESULTS ON 'B' GRANULATOR SCRUBBER INLET ON JANUARY 18, 1979, AT UREA PLANT B

Sampling Location	Test Date	Test Time	Aerodynamic Size Range, µm	Mass in Size Range, %
Scrubber Inlet	1/18/79	15:28-15:43	> 6.0	99+
Scrubber Inlet	1/19/79	10:00-10:15	> 5.7	99+
Scrubber Inlet	1/19/79	11:25-11:40	> 5.8	99+

TABLE A-22. SIX MINUTE ARITHMETIC AVERAGE OPACITY READINGS ON "B" GRANULATOR SCRUBBER STACK AT PLANT B

Date	6 Minute Time Period	Avg. Opacity for 6 min.
1-17-79	12:02 - 12:07	8.2
	12:08 - 12:13	6.3
	12:14 - 12:17	5.8
	12:20 - 12:25	5.6
	12:26 - 12:31	5.2
	12:32 - 12:37	6.5
	12:38 - 12:43	6.5
	12:44 - 12:49	6.9
	12:50 - 12:55	8.1
	12:56 - 13:01	8.1
	13:02 - 13:07	8.3
	13:08 - 13:13	7.9
	13:14 - 13:19	9.4
	13:20 - 13:25	7.3
	13:26 - 13:31	9.4
	13:32 - 13:37	8.3
	13:38 - 13:43	7.7
	13:44 - 13:49	8.3
	13:50 - 13:55	8.6
	13:56 - 14:01	7.4
	14:02 - 14:07	7.6
	14:08 - 14:13	8.4
	14:14 - 14:19	8.8
	14:20 - 14:22*	9.0
	15:50 - 15:55	9.6
	15:56 - 16:01	8.5
	16:02 - 16:07	8.5
	16:08 - 16:13	8.2
	16:14 - 16:19	9.3
	16:20 - 16:25	7.7
	16:26 - 16:31	8.0
	16:32 - 16:36*	9.7

*Less than 6 min. average.

TABLE A-23. SIX MINUTE ARITHMETIC AVERAGE OPACITY READINGS ON "B" GRANULATOR SCRUBBER STACK AT PLANT B

Date	6 Minute Time Period	Avg. Opacity for 6 min.
1-19-79	09:53 - 09:58	9.3
	09:59 - 10:04	8.5
	10:05 - 10:10	7.4
	10:11 - 10:16	8.3
	10:17 - 10:22	7.4
	10:33 - 10:28	8.1
	10:29 - 10:34	7.1
	10:35 - 10:40	7.3
	10:41 - 10:46	8.5
	10:47 - 10:52	8.5
	10:53 - 10:58	9.0
	10:59 - 11:04	8.2
	11:05 - 11:10	9.6
	11:11 - 11:16	8.3
	11:17 - 11:22	8.8
	11:23 - 11:28	8.5
	11:29 - 11:34	8.8
	11:35 - 11:40	7.9
	11:41 - 11:46	7.7
	11:47 - 11:52	7.3
1-18-79	12:44 - 12:49	9.0
	12:50 - 12:55	6.0
	12:56 - 13:01	5.0
	13:02 - 13:07	5.0
	13:08 - 13:13	5.0
	13:14 - 13:19	5.0
	13:20 - 13:25	5.0
	13:26 - 13:31	5.0
	13:32 - 13:37	5.0
	13:38 - 13:43	5.0

A.1.4 Plant C[4,5]

Testing was conducted at Plant C to determine the urea and ammonia emissions in gases exiting one of four scrubbers on a prill tower and at the inlet of a rotary drum cooler scrubber. The testing was performed during the production of fertilizer grade urea. The prill tower operates at approximately 336 Mg/day (370 tons/day) on a 24 hr/day, 7 days/week basis. The prill tower exhaust is controlled by four packed bed wet scrubbers of in-house design. The exhaust from the rotary drum cooler is controlled by a mechanically aided scrubber.

Particle size distributions were determined for the gases entering the prill tower scrubber and the rotary drum cooler scrubber. Tests performed on April 2nd and 3rd, 1979 were conducted during agricultural grade urea production. Tests performed on April 4th and 6th, 1979 were conducted during feed grade urea production. Visible emissions were conducted during both agricultural and feed grade urea productions for the outlet stacks from the prill tower scrubbers, and during agricultural grade urea production on the outlet of the rotary drum cooler scrubber. Also presented are flowrates through all four prill tower scrubbers. This is presented to verify that conditions in the single tested scrubber are representative for all four scrubbers.

Mass emission samples (April 1980) were analyzed for urea content with the p-dimethylaminobenzadehyde analysis method. Mass emission samples were analyzed for ammonia content with the specific ion electrode analysis method.

TABLE A-24. SUMMARY OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING PRILL COOLER SCRUBBER DURING FERTILIZER GRADE PRODUCTION AT PLANT C. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-23-80	04-28-80	04-28-80	
Isokinetic (%)		105	106	106	106
Production Rate (Tons/day)		281	281	281	281
Ambient Temp °F		b	b	b	57.3
Relative Humidity (%)		b	b	b	80.3
Exhaust Characteristics					
Flowrate	inlet:	7696	7102	7733	7510
(dscfm)	outlet:	b	b	b	b
Temperature	inlet:	126.6	126.7	124.4	125.9
(F°)	outlet:	b	b	b	b
Moisture (% Vol.)	inlet:	2.991	3.336	3.270	3.199
	outlet:	b	b	b	b
Control Device Characteristics					
Device Type		Entrainment Scrubber			
Pressure Drop (in W.G.)		b	b	b	b
Liquid/Gas Ration (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc.(Mg/ℓ)	inlet:	b	b	b	b
	outlet:	b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	1.531	1.243	1.353	1.413
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	107.67	75.62	89.65	90.96
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	9.197	6.468	7.686	7.450
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	0.00661	0.0105	0.0109	0.00931
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	0.436	0.638	0.723	0.599
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	0.0372	0.0545	0.0618	0.0512
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	b	b	b	b
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

a = Considered confidential by manufacturer

b = not available

TABLE A-25. SUMMARY OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING PRILL COOLER SCRUBBER DURING FERTILIZER GRADE PRODUCTION AT PLANT C. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-23-80	04-28-80	04-28-80	
Isokinetic (%)		105	106	106	106
Production Rate (Mg/day)		255	255	255	255
Ambient Temp. (K)		b	b	b	287.9
Relative Humidity		b	b	b	80.3
Exhaust Characteristics					
Flowrate	inlet:	218.0	201.1	219.0	212.7
(dsm^3/min)	outlet:	b	b	b	b
Temperature	inlet:	325.5	325.6	324.3	325.1
(K)	outlet:	b	b	b	b
Moisture (% Vol.)	inlet:	2.991	3.336	3.270	3.199
	outlet:	b	b	b	b
Control Device Characteristics					
Device Type		Entrainment Scrubber			
Pressure Drop (kPa)		b	b	b	b
Liquid/Gas Ratio (1/m^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. Mg/ℓ	inlet:	0.0243	0.0225	0.0242	0.0237
	outlet:	b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	3.733	2.845	3.096	3.224
(g/dsm^3)	outlet:	b	b	b	b
Emission Rate	inlet:	48854	34350	40700	41300
(g/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	4.599	3.234	3.843	3.725
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0151	0.0239	0.0249	0.0214
(g/dsm^3)	outlet:	b	b	b	b
Emission Rate	inlet:	197.4	289.7	328.0	271.9
(g/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	0.0186	0.0273	0.0309	0.0256
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(g/min)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

a = Considered confidential by manufacturers
b = Not available

TABLE A-26. SUMMARY OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES EXITING PRILL TOWER NORTHEAST SCRUBBER DURING AGRICULTURAL GRADE PRODUCTION AT PLANT C. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-24-80	04-25-80	04-25-80	
Isokinetic (%)		106	104	109	106
Production Rate (Tons/day)		288	300	295	295
Ambient Temp (°F) (dry bulb)		b	68	70	69
Relative Humidity (%)		b	55	52	54
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dscfm)	outlet:	13076	13730	13870	13559
Temperature	inlet:	b	b	b	b
	outlet:	77	76	77	77
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	4.779	4.584	5.676	5.020
Control Device Characteristics					
Device Type		In House Design Wet Scrubber			
Pressure Drop (in W.G.)		b	b	b	b
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%)	inlet:	127.9 E-09	118.8 E-09	127.1 E-09	124.6 E-09
	outlet:	b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	0.0127	0.00796	0.00926	0.00993
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	1.423	0.937	1.101	1.154
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	0.119	0.0749	0.0896	0.0938
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	0.0281	0.0310	0.0561	0.0384
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	3.149	3.644	6.668	4.487
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	0.262	0.152	0.542	0.319
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	b	b	b	b
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

b = Not available

TABLE A-27. SUMMARY OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES EXITING PRILL TOWER NORTHEAST SCRUBBER AT PLANT C DURING AGRICULTURAL GRADE PRODUCTION (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-24-80	04-25-80	04-25-80	
Isokinetic (%)		106	104	109	107
Production Rate (Mg/day)		262	272	268	268
Ambient Temp (K)(dry bulb)		b	293	294	294
Relative Humidity (%)		b	55	52	54
Exhaust Characteristics					
Flowrate	inlet:				
(dsm^3/min)	outlet:	370.3	342.7	388.8	383.9
Temperature	inlet:	b	b	b	b
(K)	outlet:	298	297	296	298
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	4.779	4.584	5.676	5.020
Control Device Characteristics					
Device Type			Wet Scrubber		
Pressure Drop (kPa)		b	b	b	b
Liquid/Gas Ratio (1/m^3)		b	b	b	b
Liquor pH (Ave.)		8.62	8.38	8.53	8.51
Liquor Urea Conc.(%)(Ave.)	inlet:	0.0243	0.0225	0.0242	0.0237
	outlet:	b	b	b	b
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	0.0291	0.0182	0.0212	0.0228
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	645.8	425.2	499.8	523.6
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	0.059	0.0374	0.0448	0.0471
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	0.0643	0.0709	0.0128	0.0879
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	1430	1654	3027	2037
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	0.136	0.146	0.271	0.160
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(g/min)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

a = Considered confidential by manufacturer

b = Not available

TABLE A-28. SUMMARY OF PARTICLE SIZE TESTS ON THE PRILL TOWER SCRUBBER OUTLET DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT C

Sampling Location	Test Date	Test Time	Cut Diameter Size Range, µm	Mass in Size Range %
Prill Tower Scrubber Inlet	4-2-79	1541-1556	>16.2	16.0
			10.7-16.2	2.6
			4.66-10.1	4.3
			3.0-4.66	4.5
			1.50-3.0	15.8
			0.69-1.50	20.6
			<0.69	36.2
Prill Tower Scrubber Inlet	4-2-79	1806-1813	>17.79	5.2
			11.11-17.79	0.0
			5.14-11.11	3.3
			3.31-5.14	4.1
			1.66-3.31	18.7
			0.77-1.66	50.5
			<0.77	18.2
Prill Tower Scrubber Inlet	4-3-79	0952-959	>19.88	11.5
			12.42-19.88	1.9
			5.75-12.42	2.9
			3.70-5.75	3.6
			1.87-3.70	4.9
			0.87-1.87	44.5
			<0.877	30.7
Prill Tower Scrubber Inlet	4-3-79	1145-1149	>15.01	4.9
			9.37-15.01	3.8
			4.33-9.37	3.0
			2.78-4.33	3.1
			1.39-2.78	30.0
			0.63-1.39	26.5
			<0.63	28.7

TABLE A-29. SUMMARY OF PARTICLE SIZE TESTS ON THE COOLER OUTLET AT PLANT C

Sampling Location	Test Date	Test Time	Cut Diameter Size Range, μm	Mass in Size Range %
Cooler Outlet	4-3-79	1637-1652	>17.49	98.50
			10.92-17.49	0.82
			10.92-5.05	0.54
			3.24-5.05	0.10
			< 3.24	0.0
Cooler Outlet	4-4-79	1237-1247	>16.57	99.18
			10.35-16.57	0.44
			4.78-10.35	0.31
			3.07-4.78	0.03
			1.54-3.07	0.01
			0.70-1.54	0.02
			< 0.70	0.01
Cooler Outlet	4-4-79	1745-1755	>16.87	99.17
			10.53-16.87	0.38
			4.87-10.53	0.39
			3.13-4.87	0.04
			1.57-3.13	0.00
			0.72-1.57	0.00
			< 0.72	0.02

TABLE A-30. SUMMARY OF PARTICLE SIZE TESTS ON THE PRILL TOWER SCRUBBER OUTLET DURING FEED GRADE UREA PRODUCTION AT PLANT C

Sampling Location	Test Date	Test Time	Cut Diameter Size Range, μm	Mass in Size Range %
Scrubber Outlet	4-6-79	1009-1015	> 16.61	11.9
			10.37-16.61	2.4
			4.79-10.37	7.0
			3.07-4.79	24.8
			1.53-3.07	45.6
			0.69-1.53	8.3
			< 0.69	4.5
Scrubber Outlet	4-6-79	1530-1534	>17.20	11.5
			10.74-17.20	6.7
			4.96-10.74	9.2
			3.18-4.96	22.6
			1.59-3.18	34.2
			0.72-3.18	13.2
			< 0.72	2.6
Scrubber Outlet	4-6-79	1931-1934	>15.99	12.7
			9.98-15.99	7.6
			4.60-9.98	10.6
			2.95-4.60	20.0
			1.47-2.95	28.6
			0.66-1.47	11.2
			<0.66	9.3

TABLE A-31. SUMMARY OF VISIBLE EMISSIONS FROM THE PRILL TOWER SCRUBBER DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT C

Date	6-Minute Time Period	Average Opacity
04-02-79	1400 1406	20
	1406 1412	26
	1412 1418	16
	1418 1424	13
	1424 1430	16
	1430 1436	20
	1436 1442	23
	1442 1448	21
	1448 1454	21
	1454 1500	29
	1530 1536	23.5
	1536 1542	19
	1542 1548	23.5
	1548 1554	26
04-03-79	0820 0826	12
	0826 0832	8
	0832 0838	6.5
	0838 0844	5.5
	0844 0850	6.5
	0850 0856	6.0
	0856 0904	9
	0904 0910	7
	0910 0916	6
	0916 0922	8
	0945 0951	17
	0951 0957	15
	0957 1003	18
	1003 1009	24
	1009 1015	16.5
	1015 1021	10.5
	1021 1027	13.5
	1027 1033	13.5
	1033 1039	15.5
	1039 1045	14.0
	1110 1116	22
	1116 1122	32
	1122 1128	34

TABLE A-32. SUMMARY OF VISIBLE EMISSIONS FROM THE PRILL TOWER SCRUBBER DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT C

Date	6-Minute Time Period		Average Opacity
04-03-79	1128	1134	29
	1134	1140	24
	1425	1431	5
	1431	1437	5.5
	1437	1443	4.5
	1443	1450	7
	1450	1457	4
	1457	1503	6
	1545	1551	5
	1551	1557	3
	1557	1603	6
	1603	1609	8.5

TABLE A-33. SUMMARY OF VISIBLE EMISSIONS FROM THE PRILL TOWER SCRUBBER DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT C

Date	6-Minute Time Period		Average Opacity
04-03-79	1609	1615	5.5
	1615	1621	5
	1621	1627	5
	1627	1633	5
	1633	1639	5.5
04-04-79	0845	0851	11.5
	0851	0857	9.5
	0857	0903	9
	0903	0909	13
	0909	0915	7.5
	0915	0921	2
	0921	0927	2.5
	0927	0933	7
	0933	0939	5
	0939	0945	4.5
	0946	0952	4
	0952	0958	4
	0958	1004	4
	1004	1010	5
	1010	1016	3.5
	1016	1022	3.5
	1022	1028	6
	1028	1034	6.5
	1034	1040	5.5
	1040	1046	6.0
	1046	1052	5
	1052	1058	4.5
	1058	1104	2.5
	1104	1110	3
	1110	1116	4.5
	1116	1122	10
	1122	1128	16
	1128	1134	26
	1134	1140	11
	1140	1146	6
	1146	1152	4.5
	1152	1158	10.5
	1158	1204	12.0
	1204	1210	7.0

TABLE A-34. SUMMARY OF VISIBLE EMISSIONS FROM THE PRILL TOWER SCRUBBER DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT C

Date	6-Minute Time Period		Average Opacity
04-04-79	1210	1216	8.0
	1430	1436	16
	1436	1442	11
	1442	1448	13
	1448	1454	11.5
	1454	1500	10
	1500	1506	10.5
	1506	1512	10
	1512	1518	12.5
	1518	1524	12
	1524	1530	1.5
	1600	1606	0
	1606	1612	0
	1212	1218	0.5
	1218	1224	2.5
	1224	1230	0.5
	1230	1236	1.0
	1236	1242	2.5
	1242	1248	1.0
	1248	1254	0.0
	1254	1300	1.0
04-05-79	0930	0936	6
	0936	0942	6
	0942	0948	6
	0948	0954	6
	0954	1000	6
	1000	1006	5
	1006	1012	4
	1012	1018	5
	1018	1024	6
	1024	1030	6.5
	1030	1036	5
	1036	1042	7
	1042	1048	6
	1048	1054	4
	1054	1100	7

TABLE A-35. SUMMARY OF VISIBLE EMISSIONS FROM THE PRILL TOWER SCRUBBER DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT C

Date	6-Minute Time Period		Average Opacity
04-05-79	1100	1106	9.5
	1106	1112	5
	1112	1118	6
	1118	1124	7
	1124	1130	15
	1220	1226	0.5
	1226	1232	9
	1232	1238	4
	1238	1244	4
	1244	1250	14
	1250	1256	6
	1256	1302	13
	1305	1311	6
	1311	1317	4
	1317	1323	6
	1323	1329	8
	1329	1335	9
	1335	1342	8
	1342	1348	16
	1348	1354	30
	1354	1400	37
	1400	1406	34

TABLE A-36. SUMMARY OF VISIBLE EMISSIONS FROM PRILL TOWER SCRUBBER EXIT DURING FEED GRADE UREA PRODUCTION AT PLANT C

Date	6-Minute Time Period		Average Opacity
04-05-79	1642	1648	5
	1648	1654	5
	1654	1700	5
	1700	1706	5
	1706	1712	5
	1712	1718	5
	1718	1724	5
	1724	1730	5
	1730	1736	5
	1736	1742	5
04-06-79	1100	1106	14
	1106	1112	14.5
	1112	1118	18
	1118	1124	54
	1124	1130	38
	1130	1136	32
	1136	1142	31
	1142	1148	32
	1148	1154	29
	1154	1200	31
	1206	1212	29
	1242	1248	33
	1248	1254	25
	1254	1300	22
	1300	1306	33
	1306	1312	34
	1312	1318	28
	1318	1324	26
	1324	1330	25
	1330	1336	23
	1622	1628	11
	1629	1635	15
	1636	1642	12
	1643	1649	16
	1650	1656	13
	1657	1703	13.5
	1704	1710	15
	1711	1717	13.5
	1718	1724	14.5
	1725	1731	15

TABLE A-37. VISIBLE EMISSIONS FROM ROTARY DRUM COOLER SCRUBBER OUTLET AT PLANT 'C'.

Date	6-Minute Time Period		Average Opacity
04-02-79	1400	1406	20
	1406	1412	25
	1412	1418	15
	1418	1424	20
	1424	1430	23
	1430	1436	17
	1436	1442	30
	1530	1536	25
	1536	1542	20
	1542	1548	25
	1548	1554	27

TABLE A-38. PRILL TOWER SCRUBBER OUTLET FLOW RATES* AT PLANT C

Scrubber Outlet	Time	Run 1	Run 2	Run 3	Average
Northeast	During	13070	13730	13870	13560
Southeast	Before[a]	11258	11808	12609	11892
	After[b]	**	12609	12150	12379
	Average	11258	12208	12379	12135
Southwest	Before	10496	12645	12888	12010
	After	**	12888	12798	12843
	Average	10496	12766	12843	12426
Northwest	Before	11814	12076	12902	12264
	After	**	12902	12497	12699
	Average	11814	12489	12699	12481
Total Flow[c]		46600	51200	51800	49900

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[a] Flow rates calculated from velocity traverses performed before the indicated runs.

[b] Flow rates calculated from velocity traverses performed after the indicated runs.

[c] Sum of during and average flow rates, rounded to the nearest 100 DSCFM.

*Dry standard cubic feet per minute @ 68°F, 29.92 inches Hg.
**Velocity traverse data invalid due to shut down of the prill tower.

TABLE A-39. PRILL TOWER SCRUBBER OUTLET FLOW RATES* AT PLANT C

Scrubber Outlet	Time	Run 1	Run 2	Run 3	Average
Northeast	During	370	389	393	384
Southeast	Before[a]	319	334	357	337
	After[b]	**	357	344	351
	Average	319	346	351	344
Southwest	Before	247	358	365	340
	After	**	365	363	364
	Average	297	362	364	352
Northwest	Before	335	342	366	348
	After	**	366	354	360
	Average	335	354	360	354
Total Flow[c]		1321	1451	1468	1414

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[a] Flow rates calculated from velocity traverses performed before the indicated runs.

[b] Flow rates calculated from velocity traverses performed after the indicated runs.

[c] Sum of during and average flow rates.

*Dry standard cubic meters per minute @ 293 K, 29.92 inches Hg.
**Velocity traverse data invalid due to shut down of the prill tower.

A.1.5 Plant D[6]

Testing at Plant D was conducted to determine the urea, ammonia and formaldehyde emissions from a fluidized bed prill tower during feed and agricultural grade urea production. Urea and ammonia emissions were also determined for the urea solution synthesis and concentration process main exhaust vent. The prill tower is operated 24 hrs/day, 7 days/week producing approximately 1000 Mg/day (1100 tons/day) of urea prills. Exhaust from the fluidized prill tower is ducted to eight entrainment scrubbers located on the roof of the prill tower. Two (scrubbers "A" and "C") of the eight scrubbers were tested for mass emission in the inlet and outlet gas streams. Volumetric flow rates for all eight scrubbers are presented to verify that conditions in the two tested scrubbers are representative of all the scrubbers. The urea solution synthesis and concentration process operates on a continuous basis providing urea solution for the entire urea plant. Emissions from this process are vented through a single stack and then exhausted to the atmosphere. Mass emissions were determined at the outlet of this stack.

Particle size distributions were determined for the inlet gas streams of prill tower scrubbers "A" and "C". Visible emissions were evaluated for the individual stacks of scrubbers "A" and "C" as well as for all eight scrubber stacks combined. Visible emissions were also evaluated for the outlet stack of the baghouse controlling emissions from bagging operations.

Urea emission data was determined from samples using the p-dimethylaminobenzaldehyde colorimetric method of analysis. Ammonia emissions were determined using the direct nesslerization method of sample analysis. Formaldehyde emissions were determined with the chromotropic acid analysis method.

It should be noted that preliminary velocity traverses on the scrubber inlet duct indicated that cyclonic flow existed due to axial flow fans. To account for this condition, the cyclonic flow angles were measured and the sampling probe rotated in accordance with the angle measured at each point. This is considered to be state-of-the-art procedure for these conditions.

TABLE A-40. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING PRILL TOWER SCRUBBER "A" DURING AGRICULTURAL GRADE PRODUCTION AT PLANT D. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-15-79	08-16-79	08-17-19	
Isokinetic (%)		103	102	98	101
Production Rate (Tons/day)		1044	1099	1099	1077
Ambient Temp. °F (Ave. Dry bulb)		79	79	81	80
Relative Humidity(%)		69	46	43	53
Exhaust Characteristics					
Flowrate	inlet:	65680	68880	70130	68250
(dscf/min)	outlet:	62180	60510	60530	61073
Temperature	inlet:	113	112	116	114
(F°)	outlet:	90	90	89	90
Moisture (% Vol.)	inlet:	2.382	1.881	1.844	2.036
	outlet:	3.655	3.556	3.677	3.633
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (in. W.G.)		a	a	a	a
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		a	a	a	a
Liquor Urea Conc. (lb/gal)	inlet:	a	a	a	a
	outlet:	a	a	a	a
Urea Emissions					
Particulate Conc.	inlet:	0.0699	0.0922	0.0807	0.0811
(gr/dscf)	outlet:	0.00465	0.0124	0.00868	0.00853
Emission Rate	inlet:	39.35	54.43	48.51	47.43
(lb/hr)	outlet:	2.48	6.41	4.50	4.47
Emission Factor	inlet:	0.905	1.188	1.066	1.056
(lb/ton)	outlet:	0.057	0.139	0.099	0.099
Collection Efficiency (%)		93.7	88.2	90.7	90.6
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0283	0.0375	0.0380	0.0347
(gr/dscf)	outlet:	0.105	0.118	0.0993	0.108
Emission Rate	inlet:	15.93	22.14	22.84	20.29
(lb/hr)	outlet:	56.01	61.61	51.51	56.37
Emission Factor	inlet:	0.366	0.483	0.502	0.452
(lb/ton)	outlet	1.287	1.345	1.132	1.255
Collection Efficiency (%)		<0	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet	0.000204	0.000285	0.000281	0.000257
(gr/dscf)	outlet:	.0000082	.0000102	.0000111	0.0000098
Emission Rate	inlet:	0.115	0.168	0.168	0.150
(lb/hr)	outlet:	0.00437	0.00529	0.00576	0.00513
Emission Factor	inlet:	.00264	.00368	.00371	.00335
(lb/ton)	outlet:	.000101	.000115	.000126	.000114
Collection Efficiency(%)		96.2	96.9	96.6	96.6

a = Considered confidential by manufacturer
b = Not available

TABLE A-41. SUMMARY OF MASS EMISSION RESULTS FOR UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING PRILL TOWER SCRUBBER "A" DURING AGRICULTURAL GRADE PRODUCTION AT PLANT D. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-15-79	08-16-79	08-17-79	
Isokinetic (%)		103	102	98	101
Production Rate (Mg/day)		936	1008	984	984
Ambient Temp (K) (Dry Bulb)		299	299	300	299
Relative Humidity		69	46	43	53
Exhaust Characteristics					
Flowrate	inlet:	1860	1951	1986	1932
(dsm^3/min)	outlet:	1761	1714	1714	1730
Temperature	inlet:	318	317	320	319
(K)	outlet:	305	305	305	305
Moisture (% Vol.)	inlet:	2.382	1.881	1.844	2.036
	outlet:	3.655	3.556	3.677	3.633
Control Device Characteristics					
Device Type		Entrainment Scrubber			
Pressure Drop (kPa)		a	a	a	a
Liquid/Gas Ratio ($1/m^3$)		b	b	b	b
Liquor pH (Ave.)		a	a	a	a
Liquor Urea Conc.(Mg/ℓ)	inlet:	a	a	a	a
	outlet:	a	a	a	a
Urea Emissions					
Particulate Conc.	inlet:	0.159	0.211	0.185	0.186
(g/dsm^3)	outlet:	0.0106	0.0283	0.0199	0.0195
Emission Rate	inlet:	17849	24690	22004	21514
(g/hr)	outlet:	1124	2910	2043	2030
Emission Factor	inlet:	0.453	0.594	0.533	0.528
(g/kg)	outlet:	0.0285	0.0699	0.0495	0.0498
Collection Efficiency (%)		93.7	88.2	90.7	90.6
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0647	0.0858	0.0865	0.0794
(g/dsm^3)	outlet:	0.240	0.272	0.227	0.246
Emission Rate	inlet:	7226	10040	10360	9204
(g/hr)	outlet:	25400	27940	23365	25569
Emission Factor	inlet:	0.183	0.241	0.251	0.226
(g/kg)	outlet:	0.643	0.673	0.566	0.627
Collection Efficiency (%)		<0	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	0.000467	0.000652	0.000643	0.000588
(g/dsm^3)	outlet:	0.0000188	0.0000233	0.0000254	0.0000221
Emission Rate	inlet:	52.07	76.34	76.61	68.18
(g/hr)	outlet:	1.98	2.40	2.61	2.33
Emission Factor	inlet:	0.00132	0.00184	0.00185	0.00167
(g/kg)	outlet:	0.0000503	0.0000578	0.0000633	0.0000571
Collection Efficiency (%)		96.2	96.9	96.6	96.6

a = Considered confidential by manufacturer
b = Not available

TABLE A-42. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING THE PRILL TOWER SCRUBBER "C" DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT D. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-15-79	08-16-79	08-17-79	
Isokinetic (%)		110	114	108	111
Production Rate (Ton/day)		1044	1099	1092	1078
Ambient Temp. °F (Ave. Dry bulb)		79	79	81	80
Relative Humidity (%)		69	46	43	43
Exhaust Characteristics					
Flowrate	inlet:	62360	53660	59050	58357
(dscf/min)	outlet:	56220	56450	62410	58360
Temperature	inlet:	113	111	116	113
(°F)	outlet:	86	80	82	83
Moisture (% Vol.)	inlet:	2.03	1.39	1.37	1.59
	outlet:	3.31	3.37	4.01	3.57
Control Device Characteristics					
Device Type			Impingement Scrubber		
Pressure Drop (in. W.G.)		a	a	a	a
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		a	a	a	a
Liquor Urea Conc. (lb/gal)	inlet:	a	a	a	a
	outlet:	a	a	a	a
Urea Emissions					
Particulate Conc.	inlet:	0.0464	0.0406	0.0486	0.0453
(gr/dscf)	outlet:	0.00571	0.01052	0.00985	0.00872
Emission Rate	inlet:	24.80	18.670	24.600	22.660
(lb/hr)	outlet:	2.750	5.089	5.270	4.363
Emission Factor	inlet:	0.570	0.408	0.541	0.505
(lb/ton)	outlet:	0.0632	0.111	0.116	0.0972
Collection Efficiency (%)		88.9	72.8	78.6	80.6
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0206	0.0237	0.0306	0.0248
(gr/dscf)	outlet:	0.0258	0.0400	0.0345	0.0334
Emission Rate	inlet:	11.01	10.90	15.49	12.41
(lb/hr)	outlet:	12.41	19.37	18.45	16.70
Emission Factor	inlet:	0.253	0.238	0.340	0.276
(lb/ton)	outlet	0.285	0.423	0.405	0.372
Collection Efficiency (%)		<0	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet	0.000129	0.000109	0.000139	0.000126
(gr/dscf)	outlet:	0.000003	0.00000107	0.0000088	0.00000086
Emission Rate	inlet:	0.0693	0.0500	0.0707	0.0632
(lb/hr)	outlet:	0.00305	0.00517	0.00471	0.00429
Emission Factor	inlet:	0.00159	0.00109	0.00155	0.00141
(lb/ton)	outlet:	0.000070	0.000113	0.000103	0.000096
Collection Efficiency (%)		95.6	89.7	93.3	93.2

a = Considered confidential by manufacturer
b = Not available

TABLE A-43. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING PRILL TOWER SCRUBBER "C" DURING AGRICULTURAL GRADE PRODUCTION AT PLANT D. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-15-79	08-16-79	08-17-79	
Isokinetic (%)		110	114	108	111
Production Rate (Mg/day)		948	996	990	977
Ambient Temp. (K)		299	299	300	299
Ambient Moisture (%)		69	46	43	43
Exhaust Characteristics					
Flowrate	inlet:	1776	1519	1672	1652
(dsm^3/min)	outlet:	1592	1601	1767	1653
Temperature	inlet:	418	417	420	419
(K)	outlet:	403	400	401	401
Moisture (% Vol.)	inlet:	2.029	1.395	1.371	1.598
	outlet:	3.314	3.371	4.012	3.566
Control Device Characteristics					
Device Type			Impingement Scrubber		
Pressure Drop (kPa)		a	a	a	a
Liquid/Gas Ratio (l/m^3)		b	b	b	b
Liquor pH (Ave.)		a	a	a	a
Liquor Urea Conc. Mg/ℓ	inlet:	a	a	a	a
	outlet:	a	a	a	a
Urea Emissions					
Particulate Conc.	inlet:	0.106	0.0929	0.111	0.104
(g/dsm^3)	outlet:	0.0131	0.0241	0.0225	0.0299
Emission Rate	inlet:	11249	8469	11159	10280
(g/hr)	outlet:	1247	2308	2390	1980
Emission Factor	inlet:	0.285	0.204	0.271	0.253
(g/kg)	outlet:	0.0316	0.0556	0.0579	0.0486
Collection Efficiency (%)		88.9	72.8	78.6	80.6
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0471	0.0542	0.0700	0.0567
(g/dsm^3)	outlet:	0.0590	0.0916	0.0789	0.0764
Emission Rate	inlet:	4994	4994	7026	5629
(g/hr)	outlet:	5629	8786	8369	7575
Emission Factor	inlet:	0.127	0.119	0.170	0.138
(g/kg)	outlet:	0.143	0.212	0.203	0.186
Collection Efficiency (%)					
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	0.000297	0.000249	0.000319	0.000289
(g/dsm^3)	outlet:	0.0000144	0.0000245	0.0000201	0.0000197
Emission Rate	inlet:	31.42	22.69	32.05	28.68
(g/hr)	outlet:	1.38	2.34	2.135	1.945
Emission Factor	inlet:	0.000796	0.000547	0.000777	.000701
(g/kg)	outlet:	0.0000350	0.0000560	0.0000520	.0000180
Collection Efficiency (%)		95.4	88.9	92.8	92.8

a = Considered confidential by manufacturer
b = Not available

TABLE A-44. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING PRILL TOWER SCRUBBER "A" DURING FEED GRADE PRODUCTION AT PLANT D. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-20-79	08-21-79	08-22-79	
Isokinetic (%)		104	104	102	103
Production Rate (Tons/day)		1133	1138	1102	1123
Ambient Temp. °F (Ave. Dry bulb)		87	86	82	85
Relative Humidity (%)		65	64	66	65
Exhaust Characteristics					
Flowrate	inlet:	51720	51720	53010	52150
(dscfm)	outlet:	49750	42270	50390	47470
Temperature	inlet:	189	189	182	184
(F°)	outlet:	106	103	97	102
Moisture (% Vol.)	inlet:	2.731	3.416	2.509	2.885
	outlet:	5.472	5.291	5.377	5.380
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (in. W.G.)		a	a	a	a
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		a	a	a	a
Liquor Urea Conc. (lb/gal)	inlet:	a	a	a	a
	outlet:	a	a	a	a
Urea Emissions					
Particulate Conc.	inlet:	0.0774	0.117	0.106	0.1002
(gr/dscf)	outlet:	0.00519	0.0190	0.0192	0.0142
Emission Rate	inlet:	34.31	51.96	48.07	44.79
(lb/hr)	outlet:	2.21	6.89	8.31	5.78
Emission Factor	inlet:	0.727	1.096	1.047	0.957
(lb/ton)	outlet:	0.0469	0.145	0.181	0.124
Collection Efficiency (%)		93.5	36.7	82.7	37.1
Ammonia Emissions					
Ammonia Conc.	inlet:	0.104	0.113	0.126	0.115
(gr/dscf)	outlet:	0.050	0.0591	0.0676	0.0589
Emission Rate	inlet:	46.24	50.18	57.25	51.32
(lb/hr)	outlet:	21.33	21.41	29.18	23.94
Emission Factor	inlet:	0.980	1.059	1.247	1.097
(lb/ton)	outlet	0.452	0.452	0.636	0.512
Collection Efficiency (%)		53.9	57.3	49.0	53.3
Formaldehyde Emissions					
Formaldehyde Con.	inlet	0.0000833	0.000123	0.000127	0.0001120
(gr/dscf)	outlet:	0.0000277	0.0000360	0.0000288	0.000288
Emission Rate	inlet:	0.0369	0.0547	0.0579	0.0501
(lb/hr)	outlet:	0.00968	0.0131	0.0124	0.0117
Emission Factor	inlet:	0.000782	0.00115	0.001263	0.00107
(lb/ton)	outlet:	0.000205	0.000275	0.000271	0.000250
Collection Efficiency (%)		73.8	76.1	78.5	76.6

a = Considered confidential by manufacturer
b = Not available

TABLE A-45. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING PRILL TOWER SCRUBBER "A" DURING FEED GRADE UREA PRODUCTION AT PLANT D. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-20-79	08-21-79	08-22-79	
Isokinetic (%)		104	104	102	103
Production Rate (Mg/day)		1028	10	1000	1123
Ambient Temp. (K)		304	303	301	302
Relative Humidity (%)		65	64	66	65
Exhaust Characteristics					
Flowrate	inlet:	1464	1465	1501	1476
(dsm^3/min)	outlet:	1409	1197	1427	1344
Temperature	inlet:	355	360.2	356	357
(K)	outlet:	314	313	310	312
Moisture (% Vol.)	inlet:	2.731	3.416	2.509	2.885
	outlet:	5.472	5.291	5.377	5.380
Control Device Characteristics					
Device Type			Entrainment Scrubber		
Pressure Drop (kPa)		a	a	a	a
Liquid/Gas Ratio (l/m^3)		b	b	b	b
Liquor pH (Ave.)		a	a	a	a
Liquor Urea Conc. Mg/	inlet:	a	a	a	a
	outlet:	a	a	a	a
Urea Emissions					
Particulate Conc.	inlet:	0.177	0.268	0.242	0.229
(g/dsm^3)	outlet:	0.0179	0.0435	0.0440	0.0325
Emission Rate	inlet:	15566	23569	21805	20317
(g/hr)	outlet:	1000	3126	3767	2623
Emission Factor	inlet:	0.364	0.548	0.524	0.478
(g/kg)	outlet:	0.0235	0.727	0.905	0.0618
Collection Efficiency (%)		93.4	86.7	82.7	87.1
Ammonia Emissions					
Ammonia Conc.	inlet:	0.238	0.259	0.288	0.263
(g/dsm^3)	outlet:	0.114	0.135	0.155	0.135
Emission Rate	inlet:	20970	22762	25969	23270
(g/hr)	outlet:	91675	9712	13236	1086
Emission Factor	inlet:	0.490	0.529	0.624	0.548
(g/kg)	outlet:	0.226	0.226	0.318	0.256
Collection Efficiency (%)		53.9	57.3	49.0	53.3
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	0.000191	0.000283	0.000292	0.000256
(g/dsm^3)	outlet:	0.0000519	0.0000824	0.0000659	0.0000656
Emission Rate	inlet:	16.74	24.87	26.26	22.71
(g/hr)	outlet:	4.39	5.92	5.63	5.31
Emission Factor	inlet:	0.000391	0.000577	0.000631	0.000535
(g/kg)	outlet:	0.000103	0.000138	0.000135	0.000125
Collection Efficiency (%)		73.8	76.1	78.5	76.6

a = Considered confidential by manufacturer
b = Not available

TABLE A-46. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING PRILL TOWER SCRUBBER "C" DURING FEED GRADE PRODUCTION AT PLANT D. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-20-79	08-21-79	08-22-79	
Isokinetic (%)		103	104	104	104
Production Rate (Ton/day)		1133	1131	1101	1123
Ambient Temp. °F (Ave. Dry bulb)		87	86	82	85
Relative Humidity		65	64	66	65
Exhaust Characteristics					
Flowrate	inlet:	44150	48880	46920	46650
(dscf/min)	outlet:	46270	45160	50470	47300
Temperature	inlet:	184	179	174	179
(°F)	outlet:	104	103	99	102
Moisture (% Vol.)	inlet:	3.04	2.86	2.49	2.80
	outlet:	5.83	6.39	6.19	6.13
Control Device Characteristics					
Device Type		Entrainment Scrubber			
Pressure Drop (in. W.G.)		a	a	a	a
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.		a	a	a	a
Liquor Urea Conc. lb/gal	inlet:	a	a	a	a
	outlet:	a	a	a	a
Urea Emissions					
Particulate Conc.	inlet:	0.0983	0.0942	0.104	0.0987
(gr/dscf)	outlet:	0.00682	0.0161	0.0168	0.0134
Emission Rate	inlet:	37.20	39.47	41.75	39.47
(lb/hr)	outlet:	2.70	6.23	7.27	5.43
Emission Factor	inlet:	0.788	0.833	0.910	0.843
(lb/ton)	outlet:	0.0573	0.132	0.159	0.116
Collection Efficiency (%)		92.7	84.2	82.6	86.2
Ammonia Emissions					
Ammonia Conc.	inlet:	0.129	0.106	0.108	0.114
(gr/dscf)	outlet:	0.0593	0.0533	0.0686	0.0607
Emission Rate	inlet:	48.86	44.58	43.56	45.70
(lb/hr)	outlet:	23.52	20.63	29.68	24.61
Emission Factor	inlet:	1.035	0.941	0.949	0.976
(lb/ton)	outlet	0.498	0.435	0.647	0.526
Collection Efficiency (%)		51.9	53.8	31.8	46.1
Formaldehyde Emissions					
Formaldehyde Con.	inlet	0.000100	0.000125	0.0009986	0.000108
(gr/dscf)	outlet:	0.0000241	0.0000337	0.0000283	0.0000287
Emission Rate	inlet:	0.0379	0.0523	0.0397	0.0432
(lb/hr)	outlet:	0.00957	0.0130	0.0122	0.0116
Emission Factor	inlet:	0.000803	0.00110	0.000864	0.000924
(lb/ton)	outlet:	0.000202	0.000275	0.000266	0.000249
Collection Efficiency (%)		74.7	75.0	69.2	73.1

a = Considered confidential by manufacturer
b = Not available

TABLE A-47. SUMMARY OF RESULTS OF UREA, AMMONIA, AND FORMALDEHYDE TESTS ON GASES ENTERING AND EXITING THE PRILL TOWER SCRUBBER "C" DURING FEED GRADE PRODUCTION AT PLANT D. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-20-79	08-21-79	08-22-79	
Isokinetic (%)		103	104	104	104
Production Rate (Mg/day)		1024	1032	998	1020
Ambient Temp. (K) (dry bulb)		304	303	301	302
Relative Humidity (%)		65	64	66	65
Exhaust Characteristics					
Flowrate	inlet:	1250	1384	1329	1321
(dsm^3/min)	outlet:	1310	1278	1429	1339
Temperature	inlet:	357	354	353	354
(K)	outlet:	313	312	310	312
Moisture (% Vol.)	inlet:	3.04	2.86	2.49	2.80
	outlet:	5.03	6.39	6.16	6.13
Control Device Characteristics					
Device Type		Impingement Scrubber			
Pressure Drop (kPa)		a	a	a	a
Liquid/Gas Ratio (1/m^3)		b	b	b	b
Liquor pH (Ave.)		a	a	a	a
Liquor Urea Conc. Mg/ℓ	inlet:	a	a	a	a
	outlet:	a	a	a	a
Urea Emissions					
Particulate Conc.	inlet:	0.2249	0.2155	0.237	0.2258
(g/dsm^3)	outlet:	0.0156	0.0368	0.038	0.0307
Emission Rate	inlet:	16874	17904	18938	17904
(g/hr)	outlet:	1226	2827	9299	2464
Emission Factor	inlet:	0.394	0.417	0.455	0.422
(g/kg)	outlet:	0.028	0.066	0.079	0.058
Collection Efficiency (%)		92.7	84.2	82.6	86.2
Ammonia Emissions					
Ammonia Conc.	inlet:	0.2594	0.2434	0.2478	0.2615
(g/dsm^3)	outlet:	0.1357	0.1219	.1570	0.1389
Emission Rate	inlet:	22163	20221	19759	20730
(g/hr)	outlet:	10669	9350	13463	11163
Emission Factor	inlet:	0.518	0.471	0.475	0.488
(g/kg)	outlet:	0.249	0.218	0.324	0.263
Collection Efficiency (%)		51.9	53.8	31.8	46.1
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	0.000229	0.000286	0.000226	0.000247
(g/dsm^3)	outlet:	0.0000551	0.0000771	0.0000648	0.0000657
Emission Rate	inlet:	17.201	23.719	17.985	19.605
(g/hr)	outlet:	4.341	5.917	5.543	5.278
Emission Factor	inlet:	0.000402	0.000555	0.000432	0.000462
(g/kg)	outlet:	0.000101	0.000138	0.000133	0.000125
Collection Efficiency (%)		74.7	75.0	69.2	73.1

a = Considered confidential by manufacturer
b = Not available

TABLE A-48. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES EXITING THE SOLUTION SYNTHESIS TOWER MAIN VENT AT PLANT D. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-22-79	08-22-79	08-22-79	
Isokinetic (%)		124.4	132.6	130.7	129.2
Production Rate (Mg/day)		1044	1044	1087	1059
Ambient Temp. (K)		b	b	b	b
Ambient Moisture (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dsm^3/min)	outlet:	22.26	21.01	20.95	21.41
Temperature	inlet:	b	b	b	b
(K)	outlet:	355	344	344	344
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	73.1	74.1	73.9	73.7
Control Device Characteristics					
Device Type			None		
Pressure Drop (kPa)		b	b	b	b
Liquid/Gas Ratio (l/m^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%) (Ave.)		b	b	b	b
Urea Emissions[c]					
Particulate Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	<0.196	<0.169	<0.164	<0.176
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	<262.1	<213.4	<206.1	<226.5
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	<0.00605	<0.00490	<0.00455	<0.00515
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	483.5	500.4	501.8	495.1
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	646496	631514	631968	636962
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet	14.86	14.53	13.94	14.44
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet	b	b	b	b
(g/dsm^3)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(g/min)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

b = Not available

c = Concentrations were at the threshold of detection

TABLE A-49. SUMMARY OF RESULTS OF UREA, AND AMMONIA TESTS ON GASES EXITING THE SOLUTION SYNTHESIS TOWER MAIN VENT AT PLANT D. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		08-22-79	08-22-79	08-22-79	
Isokinetic (%)		124.9	132.6	130.7	129.2
Production Rate (Tons/day)		1150	1150	1197	1166
Ambient Temp. °F (Ave. Dry bulb)		b	b	b	82
Relative Humidity (%)		b	b	b	66
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dscfm)	outlet:	786.4	742.4	740.4	756.4
Temperature	inlet:	b	b	b	b
(F°)	outlet:	180	181	181	181
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	73.1	74.1	73.9	73.7
Control Device Characteristics					
Device Type			None		
Pressure Drop (in. W.G.)		b	b	b	b
Liquid/Gas Ratio (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)		b	b	b	b
Liquor Urea Conc. (%)	inlet:	b	b	b	b
	outlet:	b	b	b	b
Urea Emissions[c]					
Particulate Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	<0.0858	<0.0738	<0.0715	<0.0770
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	<0.578	<0.470	<0.454	<0.499
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	<0.0121	<0.0098	<0.0091	<0.0103
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	211.3	218.7	219.3	216.4
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	1424	1391	1392	1403
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet	29.73	29.06	27.89	28.80
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet	b	b	b	b
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency		b	b	b	b

a = Considered confidential by manufacturer
b = Not available
c = Concentrations were at the threshold of detection

TABLE A-50. SUMMARY OF INLET PARTICLE SIZING TEST RESULTS ON SCRUBBER 'A' DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT D

Sampling Location	Test Date	Test Time	Aerodynamic Size Range, µm	Mass In Size Range, %	Cumulative Percent
A Inlet	08-14-79	1252	>13.3	48.5	
			9.17-13.3	3.4	51.5
			6.22-9.17	3.2	48.1
			4.24-6.22	2.3	44.9
			2.72-4.24	13.8	42.6
			1.36-2.72	4.0	28.8
			0.84-1.36	7.3	24.8
			0.57-0.84	6.6	17.5
			<0-57	10.9	10.9
A Inlet	08-15-79	0955	>14.5	24.9	
			10.0-14.5	9.2	75.1
			6.8-10.0	1.8	65.9
			4.63-6.8	12.8	64.1
			2.97-4.63	6.4	51.3
			1.5-2.97	10.7	44.9
			0.93-1.5	0	34.2
			0.63-0.93	20.9	34.2
			< 0.63	13.3	13.3
A Inlet	08-15-79	1126	> 1.53	17.2	
			10.6-15.3	3.0	82.8
			7.16-10.6	11.5	79.8
			4.89-7.16	7.9	68.3
			3.14-4.89	17.1	60.4
			1.58-3.14	3.0	43.3
			0.98-1.58	21.4	40.3
			0.67-0.98	14.7	18.9
			< 0.67	4.2	4.2

TABLE A-51. SUMMARY OF INLET PARTICLE SIZING TEST RESULTS ON SCRUBBER 'C' DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT D

Sampling Location	Test Date	Test Time	Aerodynamic Size Range, μm	Mass In Size Range, %	Cumulative Percent
C Inlet	08-16-79	1122	>12.3	49.0	
			8.5-12.3	0.0	51.0
			5.76-8.5	0.4	51.0
			3.92-5.76	3.0	50.6
			2.52-3.92	1.2	47.6
			1.26-2.52	11.5	46.4
			0.78-1.26	19.5	34.9
			0.53-0.78	10.8	15.1
			<0.53	4.6	1.6
C Inlet	08-16-79	1543	>12.2	21.2	
			8.4-12.2	0	78.8
			5.69-8.4	1.4	78.8
			3.88-5.69	2.5	77.4
			2.49-3.88	3.1	74.9
			1.25-2.49	22.8	71.8
			0.77-1.25	22.2	49.0
			0.52-0.77	21.2	26.8
			< 0.52	5.6	5.6
C Inlet	08-17-79	1430	>13.0	66.5	
			8.93-13.0	3.7	33.5
			6.05-8.93	0.0	29.8
			4.13-6.05	0.0	
			2.65-4.13	1.5	29.8
			1.33-2.65	0.0	28.3
			0.82-1.33	15.0	28.3
			0.56-0.82	6.0	13.3
			< 0.56	7.3	7.3

TABLE A-52. SUMMARY OF INLET PARTICLE SIZING TEST RESULTS ON SCRUBBER 'C' DURING FEED GRADE UREA PRODUCTION AT PLANT D

Sampling Location	Test Date	Test Time	Aerodynamic Size Range, μm	Mass In Size Range, %	Cumulative Percent
C Inlet	08-20-79	1555	>15.10	71.8	28.2
			10.4-15.1	0	28.2
			7.04-10.4	6.0	22.2
			4.8-7.04	3.5	18.7
			3.08-4.8	4.9	13.8
			1.54-3.08	3.4	10.4
			0.95-1.54	5.0	5.4
			0.65-0.95	0	5.4
			<0.65	5.4	
C Inlet	08-21-79	1018	>13.40	36.0	64.0
			9.22-13.4	5.4	58.6
			6.25-9.22	11.9	46.7
			4.26-6.25	8.7	38.0
			2.73-4.26	5.7	32.3
			1.36-2.73	7.2	25.1
			0.84-1.36	7.6	17.5
			0.57-0.84	7.0	10.5
			<0.57	10.5	
C Inlet	08-22-79	0935	>16.7	78.3	21.7
			11.5-16.7	0.0	21.7
			7.81-11.5	0.7	21.0
			5.32-7.81	9.4	11.6
			3.42-5.32	0.0	11.6
			1.72-3.42	6.8	4.8
			1.07-1.72	0.0	4.8
			0.73-1.07	0.0	4.8
			<0.73	4.8	

TABLE A-53. SUMMARY OF INLET PARTICLE SIZING TEST RESULTS ON SCRUBBER 'A' DURING FEED GRADE UREA PRODUCTION AT PLANT D

Sampling Location	Test Date	Test Time	Aerodynamic Size Range, μm	Mass In Size Range, %	Cumulative Percent
A Inlet	08-21-79	1605	>15.9	88.6	
			10.9-15.9	0.0	11.4
			7.4-10.9	0.0	
			5.05-7.4	0.0	
			3.24-5.05	0.0	
			1.63-3.24	5.3	11.4
			1.00-1.63	6.1	6.1
			0.69-1.00	0.0	0.0
			< 0.69	0.0	0.0
A Inlet	08-22-79	0935	>16.3	84.4	
			11.2-16.3	0.1	15.6
			7.0-11.2	0.0	15.5
			5.18-7.0	7.9	15.5
			3.33-5.18	0.0	7.6
			1.67-3.33	1.9	7.6
			1.03-1.67	0.0	5.7
			0.71-1.03	0.0	5.7
			< 0.71	5.7	5.7
A Inlet	08-22-79	1430	>14.7	98.1	
			10.1-14.7	0.0	9.1
			6.87-10.1	0.0	
			4.87-6.87	0.0	
			3.0-4.68	0.0	
			1.5-3.0	0.0	
			0.93-1.5	0.0	
			0.63-0.93	0.0	
			< 0.63	1.9	1.9

TABLE A-54. VISIBLE EMISSIONS FROM SCRUBBER 'C' OUTLET DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT D (CONT)

Date	6-Minute Time Period		Average Opacity
08-17-79	1126	1131	11.5
	1132	1137	16.3
	1138	1143	15.4
	1144	1147	10.3
	1215	1220	25.6
	1221	1226	28.3
	1227	1232	20.6
	1233	1238	27.9
	1239	1242	28.3
	1249	1254	14.0
	1255	1300	23.1
	1301	1306	31.0
	1311	1316	25.3
	1317	1322	30.7
	1329	1334	32.0
	1335	1340	40.1
	1341	1346	38.2
	1347	1352	38.0
	1353	1358	36.6
	1359	1405	36.7
	1408	1413	39.1
	1414	1419	34.0
	1420	1424	37.9

TABLE A-55. VISIBLE EMISSIONS FROM SCRUBBER 'C' OUTLET DURING AGRICULTURAL GRADE UREA PRODUCTION AT PLANT D

Date	6-Minute Time Period		Average Opacity
08-16-79	1030	1035	25.5
	1036	1041	17.7
	1042	1047	16.7
	1048	1053	20.2
	1054	1059	17.9
	1100	1105	19.4
	1106	1111	22.1
	1112	1117	20.6
	1118	1123	19.4
	1124	1129	18.8
	1215	1220	26.9
	1221	1226	27.7
	1227	1232	26.9
	1233	1238	26.9
	1239	1244	29.4
	1245	1250	28.1
	1251	1256	24.2
	1257	1302	26.7
	1303	1308	24.2
	1309	1314	35.0
	1315	1320	32.9
	1321	1326	33.8
	1327	1332	31.2
	1333	1338	23.3
	1339	1344	23.8
	1415	1420	30.8
	1421	1426	21.8
	1427	1432	28.9
	1433	1438	30.6
	1439	1444	34.8
	1445	1450	28.3
	1451	1456	37.5
	1457	1502	29.8
	1503	1508	21.3
	1509	1514	34.4
	1515	1520	35.0
	1521	1526	34.4
	1527	1532	30.4
	1533	1538	31.5
	1539	1544	34.4

TABLE A-56. VISIBLE EMISSIONS FROM SCRUBBER 'A' OUTLET DURING FEED GRADE UREA PRODUCTION AT PLANT D

Date	6-Minute Time Period		Average Opacity
08-20-79	1055	1100	19.0
	1101	1106	16.5
	1107	1112	15.9
	1113	1118	17.9
	1119	1124	12.7
	1125	1130	13.5
	1131	1136	10.9
	1137	1142	7.5
	1143	1148	5.0
	1149	1154	3.3
	1155	1200	5.8
	1201	1206	9.6
	1207	1212	7.1
	1213	1218	8.1
	1219	1224	13.1
08-21-79	0845	0850	22.3
	0851	0856	26.3
	0857	0902	29.6
	0903	0908	24.0
	0909	0914	22.3
	0915	0920	20.2
	0921	0926	-
	0927	0932	20.8
	0933	0938	21.7
	0939	0944	26.5
	0950	0955	15.4
	0956	1001	16.4
	1002	1007	20.0
	1008	1013	21.5
	1014	1019	21.7
	1020	1025	21.9
	1026	1031	28.1
	1032	1037	24.6
	1038	1043	26.7
	1044	1049	22.7

TABLE A-57. VISIBLE EMISSIONS FROM SCRUBBER 'A' OUTLET DURING FEED GRADE UREA PRODUCTION AT PLANT D (CONT)

Date	6-Minute Time Period		Average Opacity
08-21-79	1112	1117	13.8
	1118	1123	17.7
	1124	1129	28.8
	1130	1135	28.3
	1136	1141	25.0
	1142	1147	22.1
	1148	1153	20.0
	1154	1159	20.4
	1200	1205	25.2
	1206	1211	23.3
	1212	1217	23.1
	1218	1223	23.1
	1224	1229	20.0
	1230	1235	24.0
	1236	1241	21.9

TABLE A-58. VISIBLE EMISSIONS FROM SCRUBBER 'A' OUTLET DURING FEED GRADE UREA PRODUCTION AT PLANT D

Date	6-Minute Time Period		Average Opacity
08-20-79	1447	1452	6.0
	1453	1458	8.0
	1459	1504	7.0
	1505	1510	10.0
	1511	1516	5.0
08-22-79	0950	0955	14.8
	0956	1001	12.9
	1002	1007	23.5
	1008	1013	26.3
	1014	1019	28.3
	1020	1025	29.8
	1026	1031	33.1
	1032	1037	30.2
	1038	1043	32.3
	1044	1049	31.9
	1050	1055	31.3
	1056	1101	31.9
	1102	1107	29.6
	1108	1113	27.3
	1114	1119	26.5
	1120	1125	26.5
	1126	1131	28.8
	1132	1137	25.0
	1138	1143	24.4
	1144	1149	23.8

TABLE A-59. VISIBLE EMISSIONS FROM SCRUBBER 'A' OUTLET DURING FEED GRADE UREA PRODUCTION AT PLANT D (CONT)

Date	6-Minute Time Period		Average Opacity
08-23-79	0930	0935	14.0
	0936	0943	13.1
	0942	0947	15.4
	0948	0953	9.0
	0954	0959	9.6
	1000	1005	18.5
	1006	1011	13.8
	1012	1017	11.0
	1018	1023	12.9
	1024	1029	19.0
	1010	1015	24.0
	1016	1021	24.0
	1022	1027	21.7
	1028	1033	27.5
	1034	1039	25.6
	1040	1045	29.8
	1046	1051	30.0
	1052	1057	28.8
	1058	1103	29.4
	1104	1109	26.3
	1110	1115	24.8
	1116	1121	25.0
	1122	1127	24.2
	1128	1133	25.0
	1134	1139	25.8
	1140	1145	25.4
	1146	1151	24.8
	1152	1157	26.3
	1158	1203	23.8
	1204	1209	15.6

TABLE A-60. SUMMARY OF VISIBLE EMISSIONS FROM BAGGING OPERATIONS AT PLANT D

Test Location	Date	6-Minute Time Period		Average Opacity
Baghouse	12-18-79	0845	0850	0
		0851	0856	0
		0857	0902	0
		0903	0908	0
		0909	0914	0
		0915	0920	0
		0921	0926	0
		0927	0932	0
		0933	0938	0
		0939	0941	0
	12-18-79	1030	1035	0
		1036	1041	0
		1042	1047	0
		1048	1053	0.2
		1054	1059	0
		1100	1105	1.0
		1106	1111	0
		1112	1117	0
		1118	1123	0
		1124	1129	0
	12-18-79	1135	1140	0
		1141	1146	0
		1147	1152	0
		1153	1158	0
		1159	1204	0
		1205	1210	0
		1211	1216	0
		1217	1222	0
		1223	1228	0
		1229	1234	0
Baghouse	12-18-79	1340	1345	0
		1346	1351	0
		1352	1357	0
		1358	1403	0
		1404	1409	0.6

TABLE A-61. SCRUBBER INLET FLOWRATES* AT PLANT D

		FERTILIZER				FEED			
Scrubber	Time	1	2	3	Average	1	2	3	Average
A	During	65680	68880	70130	68230	51720	51720	53010	52150
B	Before[a]	59150	50320	44760	51410	34600	34910	39190	36233
	After[b]	54980	56890	50720	54197	34200	36890	39760	36950
	Average	57065	53605	47740	52803	34400	35900	39475	36592
C	During	62360	53660	59050	58357	44150	48880	46920	46650
D	Before	57970	48350	51330	52550	49140	46060	45740	46980
	After	57250	54370	51780	54467	45690	44870	46300	45620
	Average	57610	51360	51555	53508	47415	45465	46020	46300
E	Before	65330	59000	60900	61743				
	After	60010	60900	58610	59840				
	Average	62670	59950	59755	60792				
F	Before	60950	61890	62130	61657				
	After	59480	61030	57810	59440				
	Average	60215	61460	59970	60548				
G	Before	72230	69990	69230	70483				
	After	68450	70180	64820	67817				
	Average	70340	70085	67025	69150				
H	Before	56410	58540	58540	57830				
	After	56210	60140	55330	57227				
	Average	56310	59340	56935	57528				
Total[c]		492000	478000	472000	481000	178000	182000	185000	182000

[a] Flowrates calculated from velocity traverses performed before the indicated runs at scrubbers A and C.

[b] Flowrates calculated from velocity traverses performed after the indicated runs at scrubbers A and C.

[c] Sum of averages, rounded to the nearest 1000 DSCFM.

*Dry standard cubic feet per minute @ 68°F, 29.92 inches Hg.

TABLE A-62. SCRUBBER INLET FLOWRATES* AT PLANT D

		FERTILIZER				FEED			
Scrubber	Time	1	2	3	Average	1	2	3	Average
A	During	1861	1950	1987	1934	1465	1466	1502	1478
B	Before[a]	1676	1426	1268	1457	981	989	1110	1027
	After	1558	1612	1437	1536	969	1045	1127	1047
	Average	1617	1519	1353	1496	975	1018	1118	1037
C	During	1767	1520	1673	1654	1251	1385	1329	1321
D	Before	1643	1370	1455	1489	1393	1305	1296	1331
	After	1622	1541	1467	1544	1295	1272	1312	1293
	Average	1632	1455	1461	1516	1343	1288	1304	1312
E	Before	1851	1672	1726	1749				
	After	1700	1725	1661	1696				
	Average	1775	1699	1693	1723				
F	Before	1727	1754	1760	1747				
	After	1686	1730	1638	1684				
	Average	1706	1741	1699	1716				
G	Before	2046	1983	1962	1997				
	After	1940	1988	1837	1922				
	Average	1990	1985	1899	1959				
H	Before	1599	1656	1659	1639				
	After	1592	1704	1568	1622				
	Average	1596	1682	1613	1630				
Total[c]		13900	13500	13400	13600	5000	5200	5200	5200

[a] Flowrates calculated from velocity traverses performed before the indicated runs at scrubbers A and C.

[b] Flowrates calculated from velocity traverses performed after the indicated runs at scrubbers A and C.

[c] Sum of averages, rounded to nearest 100 DSCM.

*Dry standard cubic meters per minute @ 293°K, 29.92 inch Hg.

A.1.6 Plant E[7]

Testing was conducted at Plant E to determine the urea and ammonia emissions in gases entering and exiting a nonfluidized bed prill tower scrubber. The testing was done during agricultural grade urea production. (Plant E produces agricultural grade only). The prill tower operates at a production rate of approximately 272 Mg/day (300 tons/day) on a 24 hr/day, 7 day/week basis. The prill tower exhaust is ducted through a downcommer and then passed into a wetted fiber filter scrubber before being exhausted to the atmosphere. A preconditioning liquor spray is located in the downcommer prior to the entrance of the scrubber. Testing on April 15, 16, and 17 on the gases exiting the scrubber as well as the simultaneous inlet and outlet testing were performed with the preconditioning spray partially on. Testing on April 18, 21, and 22 on the gases exiting the scrubber was performed with the preconditioning spray fully on.

Particle size distributions were determined for the prill tower exhaust entering the scrubber with the preconditioning sprays partially off. Visible emissions were determined for the gases exiting the prill tower scrubber stack and rotary drum cooler scrubber stack.

Samples were analyzed for their urea content by the p-dimethylaminobenzaldehyde colorimetric (with preliminary distillation) analysis method. Samples were analyzed for their ammonia content by the specific ion electrode analysis method.

Because of the relatively short (320 min.) sampling time and low emissions in the first exiting test on April 15, 1980, the amount of urea collected was below the direction limit for the analytic method. In order to detect the urea in this sample, a larger aliquot was concentrated during the preliminary ammonia removal step. For the subsequent test runs, the sampling time was extended to 400 minutes.

TABLE A-63. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES ENTERING AND EXITING THE PRILL TOWER SCRUBBER AT PLANT E (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-15-80	04-16-80	04-17-80	
Isokinetic (%)		101	102	102	102
Production Rate (Tons/day)		293	290	290	291
Ambient Temp.(°F)		62	67	64	64
Relative Humidity (%)		42	48	55	48
Exhaust Characteristics					
Flowrate	inlet:	68010	76100	709170	74430
(dscfm)	outlet:	72910	84200	86590	80903
Temperature	inlet:	105	101	98	101
(°F)	outlet:	99	97	96	97
Moisture (% Vol.)	inlet:	0.58	1.46	1.17	1.07
	outlet:	4.81	4.98	5.06	4.74
Control Device Characteristics					
Device Type			Wet Scrubber		
Pressure Drop (in W.G.)		14.7	12.1	12.2	13.0
Liquid/Gas Ratio$_b$ (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)^b		8.7	8.8	8.8	8.8
Liquor Urea Conc.(%)(Ave.)^b		11.4	10.8	12.8	11.7
Urea Emissions					
Particulate Conc.	inlet:	0.0721	0.0466	0.0954	0.0716
(gr/dscf)	outlet:	b	0.000839	0.00128	0.00119
Emission Rate	inlet:	42.03	30.42	64.75	45.71
(lb/hr)	outlet:	b	0.606	0.534	0.570
Emission Factor	inlet:	3.5	2.4	5.4	3.8
(lb/ton)	outlet:	b	0.050	0.0782	0.0641
Collection Efficiency (%)		b	97.9	98.6	98.3
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0178	0.0167	0.0151	0.0169
(gr/dscf)	outlet:	0.103	0.112	0.0896	0.102
Emission Rate	inlet:	10.39	10.38	10.24	10.75
(lb/hr)	outlet:	64.51	80.77	66.49	70.59
Emission Factor	inlet:	0.87	0.87	0.86	0.87
(lb/ton)	outlet:	5.29	6.68	5.50	5.82
Collection Efficiency (%)		<0	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	a	a	a	a
(gr/dscf)	outlet:	a	a	a	a
Emission Rate	inlet:	a	a	a	a
(lb/hr)	outlet:	a	a	a	a
Emission Factor	inlet:	a	a	a	a
(lb/ton)	outlet:	a	a	a	a
Collection Efficiency (%)		a	a	a	a

a = not available

b = This average is for the scrubber liquor sump.

TABLE A-64. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES ENTERING AND EXITING THE PRILL TOWER SCRUBBER AT PLANT E (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-15-80	04-16-80	04-17-80	
Isokinetic (%)		101	102	102	102
Production Rate (Mg/day)		266	264	264	265
Ambient Temp (K) (Dry Bulb)		290	287	289	289
Relative Humidity (%)		42	48	55	48
Exhaust Characteristics					
Flowrate	inlet:	1926	2155	2242	2108
(dsm^3/min)	outlet:	2065	2385	2452	2304
Temperature	inlet:	313	312	311	312
(K)	outlet:	310	309	309	309
Moisture (% Vol.)	inlet:	0.58	1.46	1.17	1.07
	outlet:	4.81	4.98	5.06	4.95
Control Device Characteristics					
Device Type			Wet Scrubber		
Pressure Drop (kPa)		3.7	3.0	3.1	3.3
Liquid/Gas Ratio[b] (1/m^3)		b	b	b	b
Liquor pH (Ave.)[b]		8.7	8.8	8.8	8.8
Liquor Urea Conc.	(%) (Ave.)[b]	11.4	10.8	12.8	11.7
Urea Emissions					
Particulate Conc.	inlet:	0.165	0.107	0.218	0.164
(g/dsm^3)	outlet:	b	0.00192	0.00292	0.00247
Emission Rate	inlet:	19081	13810	29396	21603
(g/hr)	outlet:	b	0.275	0.429	0.352
Emission Factor	inlet:	1.75	1.20	2.70	7.95
(g/kg)	outlet:	b	0.0250	0.0390	0.0320
Collection Efficiency (%)		b	97.9	98.6	98.3
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0410	0.0382	0.0345	0.0387
(g/dsm^3)	outlet:	0.236	0.256	0.205	0.233
Emission Rate	inlet:	4717	4939	4649	4881
(g/hr)	outlet:	29290	36640	30160	32030
Emission Factor	inlet:	0.435	4.435	0.430	0.435
(g/kg)	outlet:	2.6	3.3	2.7	2.9
Collection Efficiency (%)		<0	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	a	a	a	a
(g/dsm^3)	outlet:	a	a	a	a
Emission Rate	inlet:	a	a	a	a
(g/hr)	outlet:	a	a	a	a
Emission Factor	inlet:	a	a	a	a
(g/kg)	outlet:	a	a	a	a
Collection Efficiency (%)		a	a	a	a

a = Not available
b = This ave. is for the scrubber liquor sump.

TABLE A-64. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES ENTERING AND EXITING THE PRILL TOWER SCRUBBER AT PLANT E (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-15-80	04-16-80	04-17-80	
Isokinetic (%)		101	102	102	102
Production Rate (Mg/day)		266	264	264	265
Ambient Temp (K) (Dry Bulb)		290	287	289	289
Relative Humidity (%)		42	48	55	48
Exhaust Characteristics					
Flowrate	inlet:	1926	2155	2242	2108
(dsm^3/min)	outlet:	2065	2385	2452	2304
Temperature	inlet:	313	312	311	312
(K)	outlet:	310	309	309	309
Moisture (% Vol.)	inlet:	0.58	1.46	1.17	1.07
	outlet:	4.81	4.98	5.06	4.95
Control Device Characteristics					
Device Type			Wet Scrubber		
Pressure Drop (kPa)		3.7	3.0	3.1	3.3
Liquid/Gas Ratio[b] (1/m^3)		b	b	b	b
Liquor pH (Ave.)[b]		8.7	8.8	8.8	8.8
Liquor Urea Conc. (%) (Ave.)[b]		11.4	10.8	12.8	11.7
Urea Emissions					
Particulate Conc.	inlet:	0.165	0.107	0.218	0.164
(g/dsm^3)	outlet:	b	0.00192	0.00292	0.00247
Emission Rate	inlet:	19081	13810	29396	21603
(g/hr)	outlet:	b	0.275	0.429	0.352
Emission Factor	inlet:	1.75	1.20	2.70	7.95
(g/kg)	outlet:	b	0.0250	0.0390	0.0320
Collection Efficiency (%)		b	97.9	98.6	98.3
Ammonia Emissions					
Ammonia Conc.	inlet:	0.0410	0.0382	0.0345	0.0387
(g/dsm^3)	outlet:	0.236	0.256	0.205	0.233
Emission Rate	inlet:	4717	4939	4649	4881
(g/hr)	outlet:	29290	36640	30160	32030
Emission Factor	inlet:	0.435	4.435	0.430	0.435
(g/kg)	outlet:	2.6	3.3	2.7	2.9
Collection Efficiency (%)		<0	<0	<0	<0
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	a	a	a	a
(g/dsm^3)	outlet:	a	a	a	a
Emission Rate	inlet:	a	a	a	a
(g/hr)	outlet:	a	a	a	a
Emission Factor	inlet:	a	a	a	a
(g/kg)	outlet:	a	a	a	a
Collection Efficiency (%)		a	a	a	a

a = Not available
b = This ave. is for the scrubber liquor sump.

TABLE A-65. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES EXITING THE PRILL TOWER SCRUBBER AT PLANT E. (English Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-18-80	04-21-80	04-22-80	
Isokinetic (%)		101	98	99	99
Production Rate (Tons/day)		295	286	300	293
Ambient Temp. (°F)		b	b	b	b
Relative Humidity (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dscfm)	outlet:	82610	85400	84210	84070
Temperature	inlet:	b	b	b	b
(°F)	outlet:	98	95	97	97
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	5.16	4.32	4.74	4.74
Control Device Characteristics					
Device Type		Wet Scrubber			
Pressure Drop (in W.G.)		12.0	12.0	12.0	12.0
Liquid/Gas Ratio[c] (gal/1000 ft^3)		b	b	b	b
Liquor pH (Ave.)[c]		8.62	8.64	8.77	8.68
Liquor Urea Conc.(%)(Ave.)[c]		13.6	14.1	13.8	13.3
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	0.000732	0.000730	0.000775	0.000745
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	0.518	0.534	0.560	0.537
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	0.0421	0.0450	0.0448	0.0440
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(gr/dscf)	outlet:	0.124	0.0984	0.0839	0.102
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	87.61	72.03	60.52	73.56
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	7.72	6.05	4.84	6.00
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	b	b	b	b
(gr/dscf)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(lb/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(lb/ton)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

b = not available

c = This average is for scrubber liquor sump.

TABLE A-66. SUMMARY OF RESULTS OF UREA AND AMMONIA TESTS ON GASES EXITING THE PRILL TOWER SCRUBBER AT PLANT E. (Metric Units)

Test No.		1	2	3	Ave.
General Data					
Date		04-18-80	04-21-80	04-22-80	
Isokinetic (%)		101	98	99	99
Production Rate (Mg/day)		268	260	272	266
Ambient Temp. (K)		b	b	b	b
Relative Humidity (%)		b	b	b	b
Exhaust Characteristics					
Flowrate	inlet:	b	b	b	b
(dsm^3/min)	outlet:	2340	2419	2385	2291
Temperature	inlet:	b	b	b	b
(K)	outlet:	310	308	309	309
Moisture (% Vol.)	inlet:	b	b	b	b
	outlet:	5.16	4.32	4.74	4.74
Control Device Characteristics					
Device Type		Wet Scrubber			
Pressure Drop (kPa)		3.0	3.0	3.0	3.0
Liquid/Gas Ratio (1/m^3)		b	b	b	b
Liquor pH (Ave.)[c]		8.62	8.64	8.77	8.68
Liquor Urea Conc.(%)(Ave.)[c]		13.6	14.1	13.8	13.3
Urea Emissions					
Particulate Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	0.00167	0.00167	0.00177	0.00171
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	234.9	242.3	253.8	243.6
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	0.0209	0.0224	0.0225	0.0225
Collection Efficiency (%)		b	b	b	b
Ammonia Emissions					
Ammonia Conc.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	0.283	0.225	0.192	0.234
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	3974	3267	2745	3329
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	3.5	3.0	2.4	3.0
Collection Efficiency (%)		b	b	b	b
Formaldehyde Emissions					
Formaldehyde Con.	inlet:	b	b	b	b
(g/dsm^3)	outlet:	b	b	b	b
Emission Rate	inlet:	b	b	b	b
(g/hr)	outlet:	b	b	b	b
Emission Factor	inlet:	b	b	b	b
(g/kg)	outlet:	b	b	b	b
Collection Efficiency (%)		b	b	b	b

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b = Not available

c = This average is for the scrubber liquor sump.

TABLE A-67. SUMMARY OF RESULTS OF THE DOWNCOMER PARTICLE SIZE TESTS AT PLANT E

Test Date	Test Time	Aerodynamic Size Range, (μm)	Mass In Size Range (%)	Cumulative (Percent)
04-16-80	1513-1520	> 3.8	80.0	
		1.71-2.81	5.8	20.0
		1.08-1.71	8.8	14.2
		0.58-1.08	4.1	5.4
		< 0.58	1.3	1.3
04-17-80	0844-0904	> 6.4	67.1	
		2.22-3.64	2.3	32.9
		1.41-2.22	8.2	30.6
		0.76-1.41	10.2	22.4
		< 0.76	12.2	12.2
04-17-80	1357-1411	>14.0	66.8	
		5.15-13.00	0.8	33.2
		3.15-5.15	2.3	32.4
		2.01-3.15	5.6	30.1
		1.10-2.01	9.2	24.5
		< 1.10	15.3	15.3

TABLE A-68. SUMMARY OF OPACITY READINGS ON THE SCRUBBER OUTLET AT PLANT E

Date	6-Minute Time Period		Average Opacity
04-15-80	1543	1548	0
	1549	1554	0.4
	1555	1600	0.2
	1601	1606	0.4
	1607	1612	0
	1613	1618	0
	1619	1624	0.2
	1625	1630	0.2
	1631	1636	0.2
	1637	1642	0.2
	1645	1650	0
	1651	1656	0
	1657	1702	0
	1703	1708	0
	1709	1714	0
	1715	1720	0.2
	1721	1726	0.2
	1727	1732	0
	1733	1738	0.2
	1739	1744	0
04-16-80	0925	0930	9.2
	0931	0936	11.7
	0937	0942	11.9
	0943	0948	6.3
	0949	0954	5.6
	0955	1000	5.0
	1001	1006	4.4
	1007	1012	2.5
	1013	1018	3.8
	1019	1024	4.0
	1034	1039	3.5
	1040	1045	3.3
	1046	1051	7.1
	1052	1057	8.5
	1058	1103	6.5
	1104	1109	7.5

TABLE A-69. SUMMARY OF OPACITY READINGS ON THE SCRUBBER OUTLET AT PLANT E

Date	6-Minute Time Period		Average Opacity
04-16-80	1110	1115	7.7
	1116	1121	4.4
	1122	1127	7.9
	1128	1133	9.2
	1158	1203	3.8
	1204	1209	3.5
	1210	1215	6.0
	1216	1220	5.3
	1248	1253	4.0
	1254	1259	5.0
	1300	1305	4.6
	1306	1311	7.7
	1312	1317	6.7
	1318	1323	8.8
	1324	1325	6.4
04-17-80	1104	1109	9.6
	1110	1115	9.2
	1116	1121	8.1
	1122	1127	6.9
	1128	1133	7.5
	1134	1139	6.3
	1140	1145	6.3
	1146	1151	4.6
	1152	1157	7.9
	1158	1203	8.8
	1205	1210	7.1
	1211	1216	7.1
	1217	1223	9.6
	1253	1258	11.5
	1259	1304	9.0
	1305	1310	6.5
	1311	1316	9.2
	1317	1322	11.7
	1323	1328	13.8
	1329	1334	15.5

TABLE A-70. SUMMARY OF OPACITY READINGS ON THE SCRUBBER OUTLET AT PLANT E

Date	6-Minute Time Period		Average Opacity
04-17-80	1340	1345	14.4
	1346	1351	11.0
	1352	1357	19.6
	1358	1403	32.9
	1404	1409	10.0
	1410	1415	10.8
	1416	1421	11.0
	1422	1427	11.9
	1428	1433	12.9
	1434	1439	11.7
	1541	1546	16.3
	1547	1552	17.1
	1553	1558	27.1
	1559	1604	20.8
	1605	1609	13.8
	1610	1613	5.4
	1617	1622	9.8
	1623	1628	6.5
	1629	1631	5.8
04-18-80	0900	0905	--
	0906	0911	--
	0912	0917	--
	0918	0923	--
	0924	0929	--
	0930	0935	--
	0936	0941	--
	0942	0947	12.8
	0948	0953	11.5
	0954	0959	14.0
	1010	1015	13.1
	1016	1021	10.8
	1022	1027	17.9
	1028	1033	12.7
	1034	1039	11.9
	1040	1045	12.3
	1046	1051	19.4
	1052	1057	11.3
	1058	1103	11.0
	1104	1109	12.9

TABLE A-71. SUMMARY OF OPACITY READINGS ON THE SCRUBBER OUTLET AT PLANT E

Date	6-Minute Time Period		Average Opacity
04-18-80	1115	1120	10.8
	1121	1126	9.0
	1127	1132	9.2
	1133	1138	12.1
	1139	1144	11.7
	1145	1150	9.6
	1151	1156	10.0
	1157	1202	13.8
	1203	1208	13.3
	1209	1214	14.8
04-21-80	1005	1010	13.5
	1011	1016	12.5
	1017	1022	17.9
	1023	1028	16.5
	1029	1034	12.3
	1035	1040	13.8
	1041	1046	8.8
	1047	1052	13.8
	1053	1058	12.7
	1059	1104	9.6
	1120	1125	11.5
	1126	1131	9.1
	1132	1137	15.4
	1138	1143	10.0
	1144	1149	8.8
	1150	1155	14.0
	1156	1201	9.8
	1202	1207	12.5
	1208	1213	12.1
	1214	1219	14.6
04-22-80	0845	0850	23.7
	0851	0856	26.9
	0857	0902	21.9
	0903	0908	19.0
	0909	0914	23.3
	0915	0920	13.5
	0921	0926	14.2
	0927	0932	12.1

TABLE A-72. SUMMARY OF OPACITY READINGS ON THE SCRUBBER OUTLET AT PLANT E

Date	6-Minute Time Period		Average Opacity
04-22-80	0933	0938	13.3
	0939	0944	14.2
	1010	1015	12.3
	1016	1021	13.1
	1022	1027	5.8
	1028	1033	10.0
	1034	1039	15.0
	1040	1045	12.3
	1046	1051	10.0
	1052	1057	8.0
	1058	1103	4.2
	1104	1109	5.7
	1110	1115	7.6
	1128	1133	9.5
	1134	1139	11.1
	1140	1145	9.8
	1146	1151	5.0
	1152	1157	6.1
	1158	1203	5.2
	1204	1209	6.1
	1210	1215	2.5
	1216	1221	5.3
	1222	1227	10.0
	1300	1305	5.0
	1306	1311	13.1
	1312	1317	9.0
	1318	1323	6.5
	1324	1329	4.4
	1330	1335	4.8
	1426	1431	6.1
	1432	1437	5.0
	1438	1443	7.7
	1444	1447	12.0
04-23-80	0920	0925	13.1
	0926	0931	19.0
	0932	0937	18.1

TABLE A-73. SUMMARY OF OPACITY READINGS ON THE SCRUBBER OUTLET AT PLANT E

Date	6-Minute Time Period		Average Opacity
04-23-80	0938	0943	26.0
↓	0944	0949	27.9
	0955	1000	31.3
	1001	1006	29.8
	1007	1012	18.8
	1013	1018	16.9
	1019	1024	19.0
	1036	1041	14.8
	1042	1047	11.3
	1048	1053	11.7
	1054	1059	11.0
	1100	1105	15.8
	1110	1115	23.1
	1116	1121	23.2
	1122	1127	24.4
	1128	1133	18.8
	1134	1139	12.3

TABLE A-74. VISIBLE EMISSIONS FROM ROTARY DRUM COOLER SCRUBBER OUTLET AT PLANT E.

Test Date	Time	Avg. Opacity for 6 min.
10-16-80	900 - 905	3.1
10-16-80	906 - 911	2.5
10-16-80	912 - 917	3.8
10-16-80	918 - 923	4.0
10-16-80	924 - 929	3.5
10-16-80	930 - 935	4.4
10-16-80	936 - 941	3.1
10-16-80	942 - 947	2.9
10-16-80	948 - 953	1.5
10-16-80	954 - 959	1.0

A.2 REFERENCES

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3. Urea Manufacture: CF Industries Emission Test Report, EMB Report 78-NHF-8, May 1979.

4. Urea Manufacture: Union Oil of California Emission Test Report, EMB Report 78-NHF-7, October 1979.

5. Urea Manufacture: Union Oil of California Emission Test Report, EMB Report 80-NHF-15, September 1980.

6. Urea Manufacture: W.R. Grace & Company Emission Test Report, EMB Report 78-NHF-3, December 1979.

7. Urea Manufacture: Reichhold Chemicals Emission Test Report, EMB Report 80-NHF-14, August 1980.

APPENDIX B
UREA EMISSION MEASUREMENT AND CONTINUOUS MONITORING

B.1 Emission Measurement Methods

B.1.1 Background

The standard method for determining particulate emissions form stationary sources is EPA Mehtod 5, whereby a particulate sample is extracted isokinetically from a source and is collected on a heated filter. The particulate mass is then determined gravimetrically. Initial evaluations by EPA and others of the applicability of Method 5 for urea sampling indicated that the standard procedures of Method 5 would not be practical.[1] Factors that affected the sampling and analysis procedures of Method 5 included the following:

- High water-solubility of urea (greater than 1 gram per ml water);
- Relatively high vapor pressure and volatility of urea melts at 133° C and will begin to decompose at lower temperatures).

As a result of these factors, major modifications to Method 5 were adopted. A summary of these modifications and the reasons for each are presented in the remainder of Section B.1.

B.1.2 Brief Summary of Urea Method Development

Industry and EPA assessments in 1977 of the applicability of Method 5 for urea sampling and analysis determined that the following modifications were necessary:

- Use of water-filled impingers as the primary urea collection devices.
- Use of a urea-specific analytical procedure for measurement of urea collected in the impinger water.

Emission tests to develop new source performance standards (NSPS) for the urea industry were begun in October 1978, using sampling and analytical procedures incorporating these Method 5 modifications. The sampling train for the first program included five impingers in series, with water in the first impinger (for urea capture), sulfuric acid in the second and third impingers (for ammonia capture), the fourth impinger empty, and the fifth impinger containing silica gel. A heated filter (filter temperature not exceeding 71°C was positioned in front of the first impinger. The filter catch was weighed and then dissolved in the water impinger contents which was then analyzed for urea with the p-dimethylaminobenzaldehyde (PDAB) procedure. Water and acid impinger contents were analyzed for ammonia by direct nesslerization.

The urea sampling and analytical procedures were further modified during the seven EPA emission tests conducted from October 1978 through April 1980. Each of these tests provided information that helped to clarify and simplify the procedures. The modifications were the result of pertinent questions raised by industry as well as investigations performed by EPA and its contractors. The in-train filter was eliminated, and urea analyses were performed by the Kjeldahl procedure, the Kjeldahl and PDAB procedures together, and eventually just the PDAB procedure.

Urea, ammonia, and formaldehyde emissions were measured during these testing programs at urea solution formation process units, solid urea formation process units (prill towers and granulators), and solid urea coolers. The results of these programs demonstrated the applicability of the recommended Method 28 for urea sampling and analysis. The modifications to Method 5 that are incorporated into the recommended method are as follows:

Sampling

- Five impingers in series with the following sequence: impingers 1, 2 and 3 each contain 100 ml water, impinger 4 contains 100 ml 1N sulfuric acid, and impinger 5 contains silica gel.
- Elimination of an in-train filter.

Analysis

- Sample Recovery: Combine the probe washes with contents of impingers 1, 2 and 3. Measure the volume of the contents of impinger 4 for moisture gain and then discard. Weigh the contents of impinger 5 for moisture gain.

- Sample Analysis: Dilute a 100 ml aliquot of the combined probe wash and water impinger contents to 500 ml, adjust the pH to greater than 9.5, then boil this solution down to about 75 ml. Dilute up to 100 ml, add PDAB cooler reagent to a 10 ml aliquot and measure color intensity in a spectrophotometer.

The PDAB procedure was determined to be the simplest and most direct procedure for urea analysis. The interfering effects of ammonia on the PDAB analysis procedure are eliminated through the boiling step, whereby ammonia is removed from the sample. Ammonia and formaldehyde sampling and analytical procedures are not included in the recommended method. The acid impinger is used to protect sampling train equipment from ammonia corrosion.

B.1.3 Detailed Development of Urea Sampling and Analysis Method

B.1.3.1. Initial Method Development

Urea sampling modifications to Method 5 were needed because of the following source conditions:

- Urea has a substantial vapor pressure even as a solid, and if a sampling is heated in a probe or on a filter for extended periods of time it would tend to decompose.[14,15]
- The high water-solubility of urea implied that a water medium in the sampling train would be an efficient urea particualte collector.
- Ammonia and formaldehyde are additional pollutants emitted from urea manufacturing processes, and both were considered secondary pollutants in the NSPS work plan. Ammonia cannot be efficiently collected in the Method 5 sampling train water impingers, so additional impingers containing acid would be required. Formaldehyde can be efficiently collected in water.

Factors that would affect urea analysis procedures were the following:

- With water impingers as the primary particulate collector, the sampling train water would have to be analyzed for urea.
- The volatility of urea would preclude rapid heating of the samples

to dryness in order to do a gravimetric analysis. At the same time, evaporating large quantities of water without heating would be inefficient and tedious.

- The insoluble fraction of particulate emitted form urea sources was considered to be insignificant.

Through literature surveys and discussions with industry sources, EPA determined that only three procedures were routinely used for urea analysis. These were the urease procedure, the Kjeldahl procedure,[5] and the PDAB procedure. With the urease procedure, urea is hydrolyzed to ammonium carbonate, the sample solution is acidified and then back-titrated with standard base. This procedure is applicable only for high concentration urea analyses, such as for scrubber liquors. The Kjeldahl procedure can be applied for urea measurement in one of two ways: direct or indirect. With the direct procedure, ammonia is boiled from a sample and the urea in the residue is converted to ammonia; this converted ammonia is distilled off and the distillate is analyzed for ammonia by either nesslerization or titration. With the indirect procedure, one sample portion is distilled and the distillate is then analyzed for ammonia. The urea in a second sample portion is converted to ammonia and this solution is distilled. This distillate is then analyzed for ammonia and the ammonia measured in the first portion is subtracted from the ammonia measured in the second portion. For both the indirect and the direct Kjeldahl procedures, urea is calculated by applying a stoichiometric conversion factor to the final ammonia measurement.

With the PDAB procedure, color reagent is added to a sample aliquot and color intensity is then related to urea concentration. This analytical procedure was chosen for the initial urea sampling and analysis method because it is simple and easy to use in the field and it will measure low levels of urea (less than 10 mg/l). The interfering affect of ammonia on the PDAB procedure[2] was of concern, and for this reason the Kjeldahl procedure was evaluated with the PDAB procedure in the early stages of the EPA emission test program.

The urea sampling and analytical procedures recommended for the EPA program included the following specific Method 5 modifications:

Sampling

- Use of five impingers in series: impinger 1 contains 100 ml deionized, distilled water; impingers 2 and 3 each contain 100 ml 1N sulfuric acid; impinger 4 is empty, and impinger 5 contains silica gel. The heated filter was retained in its position just before the first impinger.
- The probe and filter temperatures should not exceed 160°F.

Sample Recovery

Place filter in jar 1; the distilled water wash of the probe, nozzle and front half of the filter holder in jar 2; the silica gel in jar 3; and contents of impinger 1 and its distilled water wash in jar 4; the contents of impingers 2, 3, and 4 and their acid wash in jar 5.

Sample Analysis

Jar 1 - Desccate and weigh the filter, then place in 50 ml water in an ultrasonic bath. Combine this solution with jar 4.

Jar 2 - Measure the volume, then evaporate the liquid and weigh the residue. Redissolve in water and combine with jar 4.

Jar 3 - Weigh for moisture gain.

Jar 4 - Analyze for urea with the PDAB procedure.

Jar 5 - Analyze for ammonia by direct nesslerization.

Two acid impingers were employed to ensure capture of ammonia and to protect downstream sampling train equipment form the corrosive effects of ammonia. Direct nessleration[3] is a widely used ammonia colorimetric analytical procedure.

B.1.3.2 First EPA Emission Tests

At the first urea plant tested in October 1978, urea, ammonia, and formaldehyde were measured at a rotary drum granulator scrubber inlet and outlet and at a solution tower vent.[4] Formaldehyde sampling and analysis results are discussed in Section B.1.6. Sampling at the solution tower was performed with a train modified to handle the high moisture and ammonia levels in the off-gas vent: eight impingers were used (four with water, one empty, two with 10N sulfuric acid, and one with silica gel) along with an in-stack orifice.

Urea analyses were performed by the contractor using the PDAB procedure within 15 days of sample collection, and by plant personnel using the Kjeldahl indirect procedure within 24 hours of sample collection. The analyses by plant personnel were performed in order to address questions of sample stability raised by industry. The results of this testing program show the PDAB urea results exceeding the Kjeldahl results by about 8% at the granulator scrubber inlet (where ammonia concentrations were much less than the urea concentrations). At the outlet however, (where ammonia concentrations greatly exceeded the urea concentrations), the PDAB results were 48% lower than the Kjeldahl results. Urea audit sample analyses of urea standards containing varying concentrations of ammonia did indicate approximately a 2% positive interference with a 17.6 ammonia-to-urea molar ratio. The positive interference increased as the molar ratio increased. These results generally corroborated earlier evaluations of the interfering effect of ammonia on the PDAB method.[2] Other analyses of urea standards performed periodically over 10 days showed no urea degradation with time. The large difference between the PDAB and Kjeldahl analyses of the outlet samples is considered to be due to analytical errors and limitations in the Kjeldahl analysis. The PDAB procedure is more accurate than the Kjeldahl procedures at low urea concentrations.

The sampling train water impingers were purged with ambient air for 15-20 minutes at the end of each test run to flush most ammonia into the acid impingers where it would not interfere with the PDAB urea analyses. A significant amount of ammonia still remained in the water impingers, so this flushing technique was discontinued after these tests.

The results of this emission testing program showed that the amount of urea collected in the acid impingers was insignificant, indicating that nearly all sampled urea was caught in the water impinger and on the filter. Solution tower vent emissions were shown to consist primarily of water vapor and ammonia and very little urea.

B.1.3.3 Method Modifications

As a result of these first tests, EPA further modified the sampling and analytical procedures. An additional water impinger was added to insure the complete capture of urea. The filter was deleted to simplify the method (since any filter catch had been merely added to the water impinger contents) and to eliminate the possibility of an accidently overheated filter decomposing any collected area. The urea analytical procedure was changed to the Kjeldahl direct procedure (with preliminary distillation to remove ammonia). This was due to the high levels of ammonia collected in the controlled granulator emissions and the susceptibility of the PDAB procedure to ammonia interference. These modifications are summarized as follows:

Sampling

- Six impingers in series: impingers 1 and 2 each contain 100 ml water, impingers 3 and 4 each contain 100 ml 1N sulfuric acid, impinger 5 is empty, and impinger 6 contains silica gel.
- Elimination of the in-train filter.

Analysis

- Sample Recovery: Combine the probe and nozzle washes with the contents of impingers 1 and 2. Combine the contents of impingers 3, 4, and 5 in a separate container. Weigh the silica gel for moisture gain.
- Sample Analysis: Add buffering agents to the samples and distill into a boric acid solution. Analyze this distillate solution for ammonia by nesslerization. Add digestion reagents to the residue, converting organic nitrogen (urea) to ammonia. Distill and analyze this distillate solution for ammonia by nesslerization; calculate urea concentration stoichiometrically from the indicated ammonia concentration.

Several of these modifications to the urea sampling and analytical procedures were applied during the next three emission tests in December 1978, January 1979, and April 1979.

B.1.3.4 Second EPA Emission Tests

The December 1978 tests were performed at the same facility as the October 1978 tests, and consisted of emission measurements at the outlet of one granulator scrubber.[6] A major purpose of this test was to provide field samples for time stability evaluations and to attempt to establish the validity of the Kjeldahl indirect procedure analyses performed during the previous test program. The December 1978 samples were analyzed on-site for urea by the contractor using the Kjeldahl direct procedure and by plant personnel using the Kjeldahl indirect procedure.

The sampling train used in the December 1978 tests contained only 5 impingers (impingers 1, 2, and 3 contained water, impinger 4 was empty, and impinger 5 contained silica gel) because the primary concern was with urea; ammonia capture was of secondary importance. The combined contents of impingers 1 through 4 were filtered for insoluble particulate, and the filtrate was then analyzed for urea by the Kjeldahl procedures as described above and for formaldehyde as described in Section B.1.6. Ammonia analyses were also performed, by direct nesslerization and by nesslerization with preliminary distillation. The insoluble particulate catch averaged about 1.4% of the total particulate catch.

The Kjeldahl indirect analyses performed by plant personnel on the scrubber outlet samples yielded results that averaged 30% higher than the kjeldahl direct analysis results. Audit sample analyses by the contractor using the Kjeldahl direct procedure (ending with a final ammonia analysis by nesslerization) agreed within 6% of the actual urea sample weights. These same audit samples were analyzed by plant personnel using the Kjeldahl direct method ending with titration, and the results averaged 93% higher than the actual sample weights. EPA concluded that the Kjeldahl analyses performed by plant personnel during this testing program and the previous program (October 1978) were unreliable.

A complication with the use of the Kjeldahl procedures for urea analyses is the need to correct indicated urea and ammonia concentrations in order to account for the conversion of some urea to ammonia during the preliminary distillation step.[10] The standard correction factor is: 7% of the sample urea content is converted to ammonia during distillation. There is evidence, however, that this correction factor is not constant, but may vary with absolute urea concentration or with the ratio of urea to ammonia concentrations in the sample.[6,7] Use of the 7% factor produces difficulties with samples containing relatively high urea concentrations compared to ammonia concentrations; for example, with uncontrolled emission samples or scrubber liquor samples, negative corrected ammonia concentrations can be calculated. The granulator scrubber outlet samples from the December 1978 program contained relatively small amounts or urea, and no problems were encountered.

The granulator outlet samples from the December 1978 emission testing program and specially prepared urea laboratory samples were periodically analyzed over a 20-day period subsequent to the completion of the program. The purpose of these time analyses was to determine if the urea content of samples deteriorated over time. These analyses were performed with the Kjeldahl direct procedure, and the results showed no detectable change in urea content of the samples.[9] EPA concluded that there would be no problems with the stability of urea samples analyzed up to 20 days after the sample collection.

B.1.3.5 Third and Fourth EPA Emission Tests

The January 1979 and April 1979 emission tests were performed with the modified urea sampling and analytical procedures (6 impingers, Kjeldahl direct analysis procedure). Emissions at a granulator scrubber inlet and outlet and at a solution tower vent were measured during the January 1979 tests.[7] Ammonia analyses were performed by both the direct nesslerization and the nesslerization with preliminary distillation procedures. The granulator inlet samples contained relatively large urea concentrations and, as a result of the urea to ammonia conversion, the two ammonia analytical procedures differed greatly in indicated ammonia concentrations. No significant difference occurred with the outlet samples. Formaldehyde analyses were also performed, as described in Section B.1.6. The urea content of the acid impingers was less than 0.2% of the total urea caught at the granulator scrubber inlet and near the threshold of detection at the outlet.

During the April 1979 tests, prill tower uncontrolled and controlled emission samples were analyzed by both the Kjeldahl and the PDAB procedures.[8] Procedural difficulties during the analyses, however, prevented any reliable evaluation of the results.

B.1.3.6 Method Modification

At this time, the urea sampling and analytical procedures were further modified, based on the results of these three recent emission tests. Ammonia and formaldehyde sampling was discontinued because no immediate need for emission standards for these pollutants was foreseen. The PDAB procedure was retained for the urea analyses because of its advantages (its simplicity and the fact that it measures urea directly) and because of the disadvantages of the Kjeldahl procedure. Its complexity, the number of reagents and amount of apparatus needed, as well as the problems associated with the urea to ammonia conversion during distillation, were the major reasons for deleting the Kjeldahl procedure.

The problem of ammonia interference in the PDAB procedure was investigated in more detail at this time.[9] The interfering effects of ammonia as initially described in the literature[2] and as discussed above were corroborated. Investigations with prepared laboratory standard solutions showed a slight (less than 2%) positive interference for approximately a 20:1 ammonia to urea molar ratio. Higher molar ratios increased the interference. To eliminate the ammonia interference during the field sample analyses, a preliminary distillation step was included in the PDAB procedure, whereby ammonia is boiled off prior to the actual analysis.

The modifications to the urea sampling and analytical procedures made at this time are summarized as follows:

Sampling

- Five impingers in series: impingers 1 and 2 each contain 100 ml water, impinger 3 contains 100 ml 1N sulfuric acid, impinger 4 is empty, and impinger 5 contains silica gel.

Analysis

- Sample Recovery: Combine the nozzle and probe washes with the contents of impingers 1 and 2. Mesaure the voluje of the contents of impingers 3 and 4, then discard. Weigh the silica gel for moisture gain.
- Sample Analysis: Dilute a 100 ml aliquot to 500 ml, adjust the pH to greater than 9.5, then boil sample down to about 75 ml. Dilute up to 100 ml, and add PDAB color reagent to a 10 ml aliquot and measure color intensity in a spectrophotometer.

The one acid impinger was retained to protect the downstream sampling train equipment from the corrosive effects of ammonia. During the final three emissions tests, ammonia sampling and analysis was continued in order to accumulate background data for potential future use. An dditional acid impinger was therefore added to the train immediately preceding the empty impinger, making a total of six impingers in the train.

B.1.3.7 Fifth, Sixth, and Seventh EPA Emission Tests

The fifth emission tests were performed in August 1979 on uncontrolled and controlled prill tower emissions and on emissions from a solution tower vent.[11] The sampling and analytical procedures described immediately above were used (6 impingers, PDAB procedure). The water impinger contents were filtered prior to urea, ammonia, and formaldehyde analyses to retain any insoluble particulate. Water and acid impingers were analyzed for urea by PDAB procedure with preliminary distillation, and for ammonia by both direct nesslerization and specific ion electrode. The two ammonia analysis results agreed with each other within 10%. The urea content of the acid impingers was negligible (at the threshold of detection) for both controlled and uncontrolled prill tower emissions samples.

During the urea analysis of the first series of the first series of water and acid impinger samples, the analyst determined that sulfuric acid was acting as a negative interference to the PDAB urea analysis. In order to compensate for this interference, urea standards used to establish absorbance vs. concentration calibration curves were prepared with the same acid concentrations as the samples being analyzed.[9,11]

The effect of the preliminary distillation step (boiling ammonia off) was investigated during this field program as part of the audit sample analyses. The investigation results indicate that the extent of urea loss during the distillation step is 12 to 14 percent. This urea loss can be compensated for as long as both samples and standards are handled in the same way (both undergo distillation).[9]

Prior to the sixth emission tests, the absolute threshold of detection for the PDAB urea analysis procedure was investigated with laboratory standard solutions and was determined to be 5 to 7 mg/l.[9] The sixth set of emission tests were performed in April 1980 on uncontrolled and controlled prill tower emissions.[12] It was known beforehand that the controlled prill tower emissions would be very low, so an unusually long sampling time was planned (320 minutes). Even with this extended sampling time the first samples yielded urea concentrations near the threshold of detection. Consequently, sampling times were further extended (400 minutes) to collect more urea, and the PDAB analysis procedure was modified in order to assess the low concentrations. Instead of diluting a 100 ml sample aliquot to 500 ml and then boiling down to 75 ml, larger sample aliquots (500 to 700 ml) were taken and boiled down without dilution. In this way, 5 to 7 times as much urea was concentrated in the same volume and the sensitivity of the analysis method was effectively increased.[9,12]

The urea content of the acid impingers was about 2.5% (less than 10 mg) of the total urea catch at the scrubber inlet (uncontrolled emissions) and at or below the threshold of detection at the scrubber outlet (controlled emissions). Ammonia analyses were performed with the direct nesslerization procedure and with the specific ion electrode (SIE) procedure. The results of both analysis procedures agreed within 6 percent.

The stability of urea field samples was further documented during this emission testing program. The urea analyses of the scrubber outlet samples were performed in the field within 24 hours of sample collection and at the contractor's laboratory within 16 days of sample collection. No significant difference existed between the results.

The last EPA emission tests were conducted in April 1980 on the outlet of a prill tower scrubber and on the inlet of a prill cooler scrubber.[13] One purpose of this program was to document the urea collection efficiency of the sampling train (six impingers: 1 and 2 water, 3 and 4 acid, 5 empty, and 6 silica gel). The nozzle and probe wash, the contents of impinger 1, the contents of impinger 1, the contents of impinger 2, and the combined contents of impingers 3, 4, and 5 were analyzed separately for urea (PDAB procedure with ammonia removal) and ammonia (SIE procedure). The analysis results showed that 70% of the urea is caught by the probe and first water impinger, and the remaining 30% is caught by the second water impinger. The urea content of the acid impingers was below the threshold of detection. The ammonia analysis results showed that about half the ammonia is caught in the water impingers and half in the acid impingers.[9,13]

During several of the EPA emission tests, acid impinger samples turned turbid when the PDAB color reagent was added, due perhaps to the amount of sodium hydroxide added to adjust the sample pH. In all cases, however, the turbidity was removed with the addition of a small amount (1 or 2 ml) of concentrated hydrochloric acid.[11,12,13]

B.1.3.8 Recommended Method

The recommended urea sampling and analysis method (Method 28) incorporates an additional modification to the sampling train, based on the results from all the EPA emission tests and the urea method development investigations. These final method modifications are summarized as follows:

Sampling

- Five impingers in series with the following sequence: impingers 1, 2, and 3 each contain 100 ml water, impinger 4 contains 100 ml 1N sulfuric acid, and impinger 5 contains silica gel.

Analysis

- Combine the probe washes and the contents of the three water impingers and analyze for urea by the PDAB procedure with ammonia removal.
- Measure the volume of the contents of impinger 4 for water gain and discard. Weigh the contents of impinger 5 for water gain.

The third water impinger is included to ensure capture of all sampled urea and to eliminate the need to make up separate urea standards for acid impinger sample analysis. (As discussed above, the acid content of samples and standards should be the same.) The acid impinger is included to protect the sampling train equipment from ammonia.

In situations where ammonia sampling is desired, an additional impinger (containing 100 ml 1N sulfuric acid) can be added to the train directly preceding the silica gel impinger. In this case, the combined contents of the first three impingers are analyzed for urea (by PDAB) and ammonia (by SIE or direct nesslerization), and the combined contents of impingers 4 and 5 are analyzed for ammonia only.

The results of the urea EPA emission tests have demonstrated the utility and economy of the recommended method. The urea (and ammonia) analytical procedures require a minimum amount of equipment and field laboratory space. All analyses can be performed on-site and immediately after each individual test run. The ability to perform sampling analyses quickly in the field allows for rapid evaluation of emission values and sampling technique.

B.1.4 Potential Problems with the Recommended Method

Two difficulties may be encountered with the use of the recommended Method 28:

- Decomposition of urea in the probe at elevated temperatures;
- Incomparability of Method 28 data and Method 5 data.

By maintaining probe temperatures at about 6°C above stack temperature, sample decomposition and moisture condensation in the probe can be avoided. Most emission control devices operate at or near saturation and with outlet gas stream temperatures less than 49°C. Solid urea melts at about 133°C but will decompose at temperatures below the melting point. Routine analyses of the urea product by industry that show the presence of biuret indicate that decomposition does take place. Industry procedures for drying solid urea specify heating at 70°C overnight. Therefore, to ensure the integrity of a sample, a reasonable upper limit on probe temperature is approximately 71°C.

A source subject to particulate emission regulations normally undergoes periodic compliance tests. Method 28 would be used specifically to verify the particulate emission compliance of a new urea source. The results of a Method 28 urea compliance test could not be directly compared to the results of a Method 5 urea compliance test because of the factors discussed in Section B.1.3. In addition, the relationship between Method 5 urea collection and Method 28 urea collection is not established. This relationship would depend on the type of emission source, the operating conditions of that source, and the amount of urea particulate caught. Small amounts of particulate (for example, less than 10 mg) can be analyzed accurately by Method 28, but are difficult to assess with a Method 5 gravimetric analysis.

B.1.5 Relationship of Data Gathered Under EPA Tests to Data Gathered with the Recommended Test Method

The majority of the EPA emission tests were conducted using the same sampling and analytical procedures as contained in the recommended Method 28. The first tests and the last three tests (all utilizing the PDAB analysis method) differed from each other in that the first tests did not include an ammonia removal step and did utilize an in-train filter. Since the ammonia-to-urea molar ratio in the samples of the first tests did not exceed 20, the urea analysis results of these samples would not be in error by more than approximately 2 percent due to ammonia interference. The in-train filter catch was redissolved in the water impinger contents and so was included in the urea analysis results. The second, third, and fourth emission tests utilized the Kjeldahl urea analytical procedure. The data gathered during these three tests may be in error by approximately 7 percent due to the urea-to-ammonia conversion that occurs during distillation. Urea audit sample analyses performed during these tests showed that the Kjeldahl procedure produced results within the required accuracy (±10 percent). The results of the fourth tests are not considered valid, as noted in Section B.1.3.

B.1.6 Formaldehyde Sampling and Analysis During the EPA Tests

A formaldehyde-based additive is often used in urea production processes to coat solid urea prills. Formaldehyde emissions were sampled and analyzed through the August 1979 EPA emission tests. Formaldehyde emissions were very low, and subsequently formaldehyde sampling was discontinued.

During the first EPA test, formaldehyde at the granulator scrubber inlet and outlet was sampled with a sampling train separate from the train used for the urea and ammonia sampling.[5] The procedure in the EPA document "Tentative Method for Isokinetic Determination of Pollutant Levels in the Effluent of Formaldehyde Manufacturing Facilities" was followed, which utilized the impinger sequence of Method 5 but without a filter. Formaldehyde analysis was performed with the chromotropic acid procedure. The analytical results showed that formaldehyde emissions at the granulator scrubber inlet and outlet were about 0.045 and 0.023 kg per hour, respectively.

During the second EPA test in December 1978, the urea sampling train impinger contents were analyzed for formaldehyde with the chromotropic acid procedure.[6] Formaldehyde emissions from this granulator outlet averaged less than 0.36 kg per hour.

The same formaldehyde sampling and analysis procedures that were followed in the second EPA test were followed in the third and fifth tests (an aliquot from the urea sampling train impingers were analyzed). During the third test, formaldehyde emissions in the granulator scrubber inlet and outlet were approximately 0.09 and 0.045 kg per hour, respectively.[7] During the fifth test, prill tower scrubber inlet and outlet formaldehyde emissions averaged less than 0.045 and 0.0045 kg per hour, respectively.[11]

TABLE 1

MANTIME BREAKDOWN FOR COMPLIANCE TEST

Task	Number of People	Number of Days	Total Man-Days
Site Visit	1	1	1
Field Work	2	1	2
Preparation and Cleanup	1	2	2
Lab Analysis	1	2	2
Data Reduction	1	0.5	0.5
Report Preparation	1	2	2
Management	1	0.5	0.5
		Total	10

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